

INFRARED IMAGE TRANSMISSION STUDY

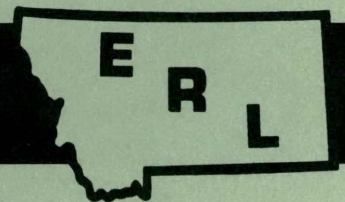
FINAL REPORT

ERL REPORT #1575

MONTANA STATE UNIVERSITY

Electronics Research Laboratory

BOZEMAN, MONTANA



INFRARED IMAGE TRANSMISSION STUDY

FINAL REPORT

ERL REPORT #1575

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ABSTRACT

The following paper is a final report on a study to determine the best way of transmitting infrared scanner data to the ground from an aircraft flying over a fire camp. Typical items considered were: airplane flight path over the camp, altitude, aircraft velocity, the type of antenna on the plane and on the ground, and real time or compressed time data transmission. A major portion of the effort was spent in comparing an analog transmission with a digital transmission system. The report includes a complete analysis of a PCM type digital system with the results showing a PCM system does not appear feasible, at least without a number of system restrictions.

Appendix A of the report contains an extensive catalog of possible transmission systems complete with manufacturers' names, model numbers, equipment costs (as of 1 April 1975), and a technical analysis of the expected performance of each system. The two variables are the carrier frequency and the signal base bandwidth. Each system is set up to meet the overall system specifications listed in Interim Report #3 (Appendix D of this report). The report makes recommendations as to what type of rf system to use as well as how to do the signal processing.

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I. INTRODUCTION

This is the fourth and final report for Supplement 25 to 12-11-204-12. The major portion of the work discussed took place from 1 February 1975 through 15 June 1975. The original contract was to end on 1 April 1975, but this was extended to 30 June 1975 by mutual agreement between Forest Service personnel and the research team at Montana State University. The extension allowed a new approach of transmitting the data to be thoroughly studied. This approach was suggested about 1 April and arose as a result of the research done up to that point.

The major thrust of this report will be to put all the information gathered on the project into a form that will be of maximum use to Forest Service personnel. Some of the information is in a "system catalog" form and as such, appears in Appendix A. This is not to suggest the information contained therein is of little importance. On the contrary, it forms a major part of the report. However, due to the sheer volume of data contained in this "catalog", the logical spot for its inclusion is in the Appendix.

A few curves and data are referred to that are contained in earlier reports. These data are on file with the Forest Service and, hence, are not reproduced in this report. However, Reports #2 and #3 are attached as Appendices C and D for convenience.

II. TECHNICAL CONSIDERATIONS

As with previous reports, this section will be divided into two major sections. These are: the rf transmission section and the signal processing section.

A. Radio Frequency Transmission

The general system parameters were established earlier and appeared in Interim Report #3. These general specifications were used to establish the specific equipment types shown in the rf system catalog. Part of the work done during this last period was to establish available frequency bands that might be used for this system. The result is shown in Table I.

Table 1
FREQUENCY BANDS SPECIFIED FOR GOVERNMENT USE

<u>Band Number</u>	<u>Frequency Range (MHz)</u>
1	410-420
2	902-928
3	1350-1400
4	1710-1850
5	2200-2290
6	2700-2900
7	4400-4990
8	7125-8400

The frequency bands were taken from Federal Communications Commission (FCC) Rules and Regulations, Volume II, September 1972, as amended in Transmittal

Sheet #5. These frequencies were then considered as part of the rf system specifications and complete systems were put together for each band and for several base signal bandwidths within each band. An example is shown on the following two pages. On the first page, the carrier frequency is shown along with the bandwidth at the top of the page. Listed below is the necessary data for the rf portion for the system including manufacturer, type of equipment, model number, and cost of the item. It should be pointed out that the manufacturers listed were picked because their items met the necessary specifications, the items were off-the-shelf, and as a third criteria, these manufacturers are generally known for quality and ability to meet the specifications listed for their products. A fairly extensive survey of available gear was conducted and those products listed appeared to fit all the necessary requirements.

The second page of the example from the "system catalog" shows the path transmission calculations using the specifications for the equipment from the first page. The expressions and block diagram for doing the path loss calculations appeared in both Interim Reports #2 and #3. This is simply a power budget starting at the transmitter and adding gain (or subtracting loss) to get an expected signal level at the ground station receiver. The final figure in db is the fade margin. This figure indicates the amount that the signal from the plane could fade (lose amplitude) and still be detected and usable at the receiver. Notice then in the example, that the fade margin was 37.3 db, well above the required 20 db. The second column of figures represents the same equipment, but calculations were done for a 50-mile path rather than a 20-mile path. The fade margin still came out 29 db. Note that this was for a

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 410-420 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D00100
Price: \$230

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620P
Price: \$3,100

Receiver:

Manufacturer: AACOM
Model Number: AR-400P
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$10,437

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz - 500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	115.1	123.1
Total System Gains (db):	55.0	
Total System Losses (db):*	116.7	125.0
Median Received Signal (dbm):*	-61.7	-70.0
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	37.3	29.0

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

20-watt transmitter and a 9-db gain ground antenna. Due to the narrow bandwidth requirement (50 kHz) the receiver threshold was -99 dbm and, hence, the favorable fade margins. As the bandwidth increases, more signal must reach the receiver terminals to be detected and usable. For instance, note for band one and a 50 kHz bandwidth the fade margin for a 50-mile path is 29 db while for the same band and path, but a 500-kHz bandwidth the fade margin is 20 db.

In general, the cost of the complete rf system goes up with increasing frequency and increasing bandwidth. The two are not entirely independent, but for instance, if a system is both high in frequency and requires a wide bandwidth, it will cost more than a lower frequency, narrow band system. There are trade-off areas here obviously. One could go to higher frequencies, but narrow bandwidths to achieve a cost goal. Or one could choose lower frequencies to allow more bandwidth options at some fixed cost level. The latter is recommended. It seems reasonable to be as flexible as possible at this stage of the system design.

1. Recommended Transmission System

The number of systems cataloged in Appendix A shows the rather large variety of choices that are possible within the specifications as listed in Interim Report #3. Partially, this is due to the general nature of the specifications and the inability to firmly state a carrier frequency and system bandwidth. Part of the variety also arises due to the fact that there are several ways to achieve the required specifications. This section will be concerned with recommending as specifically as possible an rf transmission system.

All the rf gear listed is frequency modulated (FM) and can be used for analog transmission or pulse code modulated (PCM) transmission. If a PCM system is finally chosen, the gear listed operates with frequency shift keying (FSK). The discussion on analog vs PCM transmission appears in the section on signal processing. In either case, it can be stated that FM modulation is recommended because it offers a greater signal-to-noise ratio at signal levels greater than the FM improvement threshold than does an amplitude modulated (AM) system or single-sideband (SSB) system at comparable levels.

Only two rf power levels are recommended, either 20 or 40 watts at the transmitter. Generally speaking, the lower the transmitter power, the lower the system cost and the lower the chances are of causing interference with other users. On some of the higher frequency systems or where wide bandwidths were used, a 40-watt transmitter was needed to meet the 20-db fade margin specifications. It is recommended that the smallest possible bandwidth be used in conjunction with as low a frequency as possible.

The size and weight of both the airborne system and the ground system will change somewhat depending on the choice of carrier frequency. The major components that change size rapidly with frequency are the two antennas. For all the systems listed, however, the ground antenna is never larger than a 4-foot-diameter parabola and the airborne antenna is always a quarter wave stub in the form of a blade to maintain a clean airplane profile. The stub antenna for the plane is the logical choice since it is small, fairly cheap, and its radiation pattern [see Interim Report #3, (Appendix D)] offers the best footprint for ground acquisition. To

assure ground acquisition, the ground antenna must have a fairly wide beamwidth, but also it must have a moderately high gain. The antennas picked reflect these two restrictions. Only two types of ground antennas are recommended, i.e., a parabolic dish or a small log periodic antenna.

The recommended specification on the receiver threshold is approximately 35 db ($\frac{\text{signal in}}{\text{noise in}} \approx 35 \text{ db}$) at the median received signal level. This number was picked based on conversations with leading manufacturers of rf receivers. Each of the receivers listed meets this specification in conjunction with the 20-db fade margin specification.

In summary, no one system is given a total recommendation since at this point, the requirements simply are not defined well enough. General recommendations are given, however.

1. The carrier frequency should be picked as low as possible.
2. The base signal bandwidth should be as narrow as possible.
3. Frequencies in the 6 GHz to 20 GHz range are not recommended due to rapidly increasing systems cost in this range, gear is not as readily available in this range, and there is no compelling technical reason to go to these frequencies.
4. A very wide choice of systems is given in the rf systems catalog, one of which will surely fit the bill when final systems specifications become clearly defined.

5. The aircraft antenna should be mounted in the center of the belly of the aircraft and as nearly as possible half way between the leading and trailing edges of the wings. There should be no obstructions (such as other antennas) in front of the downlink antenna. This should give optimum performance from the downlink antenna.
6. A number of recommendations were made and discussed in Interim Report #3 (see Appendix D). One of these was for a specific recorder (the Model R-540-0001 by Emerson Electric). This recorder was recommended since it had a variable tape speed which would allow the data to be transmitted at a faster rate than it was recorded. Speeding the rate of transmission allows better utilization of aircraft time, less time on the prescribed path, and less chance of interference with other users of the frequency band. It should be pointed out that any of the rf gear listed may be used with this recorder at any of its tape speeds.

B. Signal Processing Section

The previous interim reports have discussed various aspects of the signal processing with the major emphasis on an analog system. During the past work period, a digital communications system was investigated. This was one of the reasons for extending the contract work period. A major portion of the next section will, therefore, be devoted to a detailed

discussion of a digital system. It was assumed that not everybody was familiar with digital systems and, hence, some time is devoted to discussing basic digital communications. Following this is a more detailed discussion of a type of system called Pulse Code Modulated (PCM) which appeared to hold promise as applied to infrared data transmission. Certain criteria are developed which would have to be met by the final transmission system to allow PCM to be successfully employed.

1. Digital Data Communications Considerations

Heretofore we have considered analog signals and analog signal communication systems. A band limited analog signal can be completely specified by a series of samples taken adequately often. The Nyquist Sampling Theorem says that if the highest frequency present in a signal is $f_{\max}$, then the signal can be reconstructed if sampling occurs at a rate greater than $2 f_{\max}$ samples per second. A sketch of an analog signal and its samples are shown in Figure 1. (The Nyquist rate is assumed.)

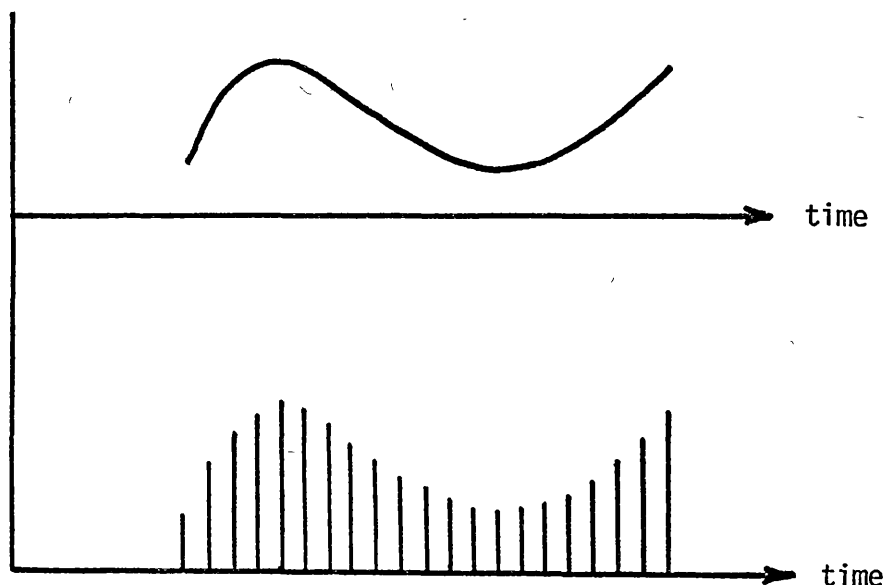


Figure 1

Analog Signal And Its Samples

It is not generally obvious how the original signal can be regained from a series of samples. Consideration has to be given to the nature of the original signal frequency spectrum and to the frequency spectrum of the samples. The frequency spectrum of an original signal $[G(f)]$ and its samples are shown in Figure 2. Again, the Nyquist sampling rate is assumed.

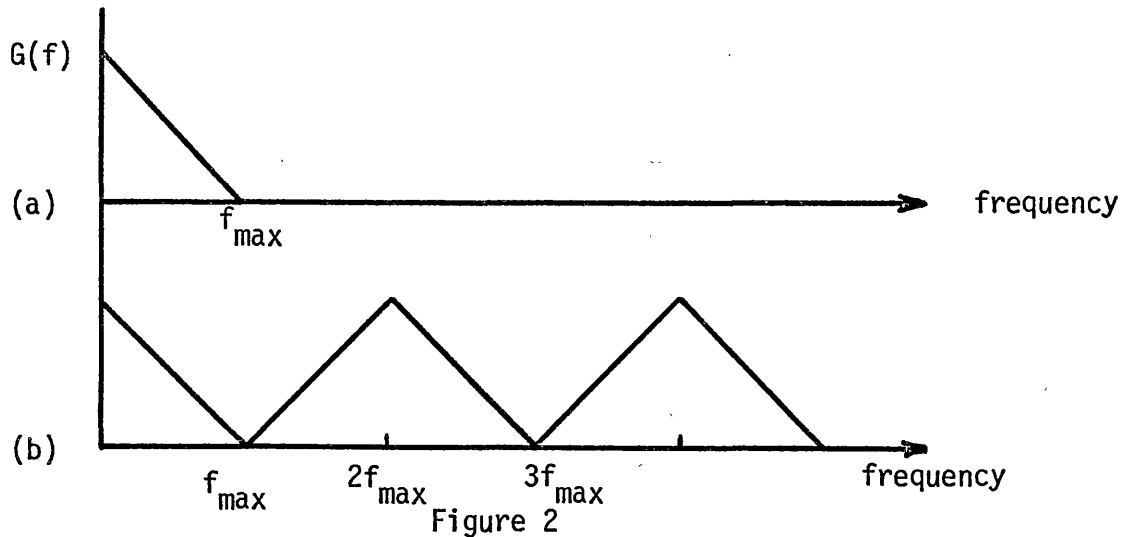


Figure 2
Frequency Spectrum of Original Signal (a)
And of Samples (b)

After the original low frequency spectrum, the sample spectrum continues repeating a double-side-band suppressed carrier type of modulation spectrum where each suppressed carrier occurs at an integer multiple of the sampling frequency. (Note the double-side-band suppressed carrier modulation spectrum between $f_{\max}$ and $3f_{\max}$.) To regain the original signal, the samples need to be passed through an idealized low-pass filter with a cut-off frequency at $f_{\max}$. The characteristics of such a filter are shown in Figure 3.

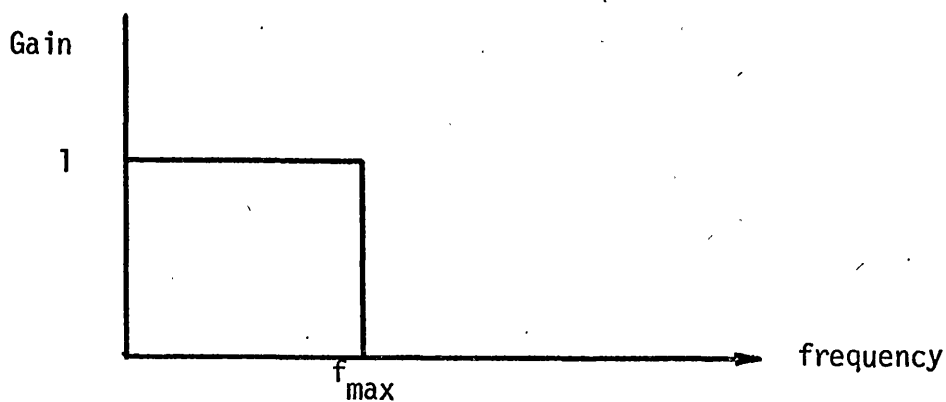


Figure 3

Idealized Low-Pass Filter

Then when the samples are passed through the low-pass filter, only the desired analog signal results. The problem arises, however, in that there are no idealized low-pass filters. Real low-pass filters have characteristics as shown in Figure 4.

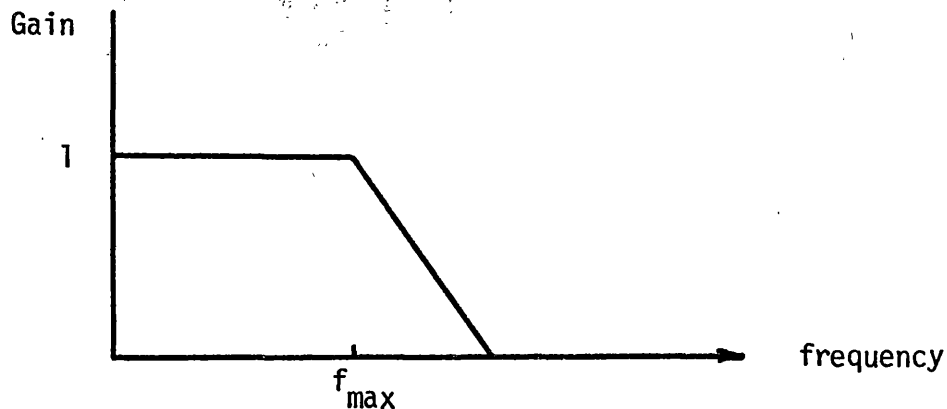


Figure 4

Real Low-Pass Filter

When a series of samples, such as shown earlier, is passed through such a low-pass filter, the output is a very distorted representation of the original signal. It is distorted because high frequency components from the double-side-band suppressed carrier signal centered at $2 f_{\max}$ can pass

through the low-pass filter. The solution to this problem is to sample at a rate greater than the Nyquist rate. This establishes a guard band where no signals are present and a real low-pass filter can produce the desired analog signal. If the signal sampled earlier had been sampled at twice the Nyquist rate, the spectrum of the samples would have appeared as in Figure 5.

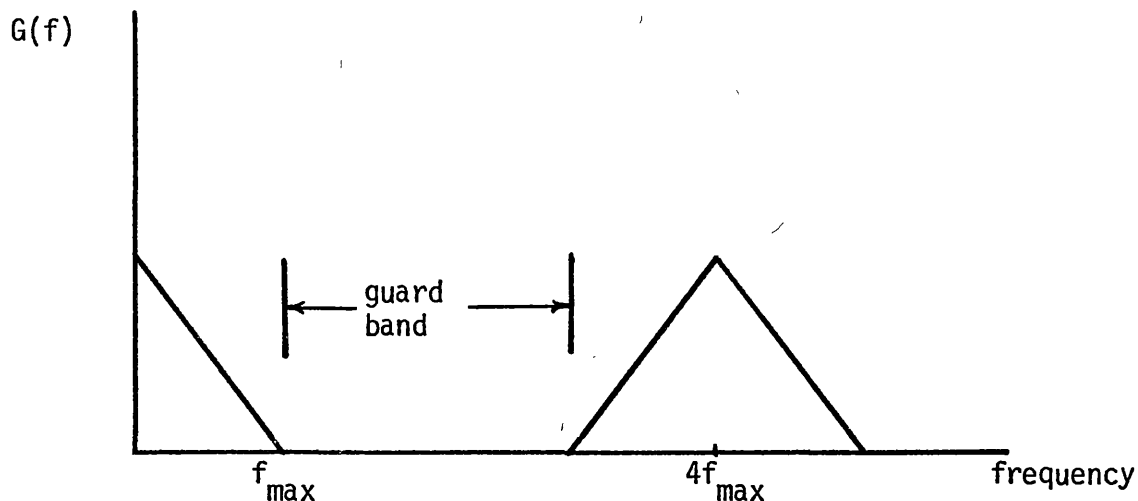


Figure 5

Frequency Spectrum of Samples Taken
at Twice the Nyquist Rate

Communication systems using sampled signals generally sample at a rate between 1.2 to 2 times the Nyquist sampling rate. The slower the sampling rate, the more elaborate and expensive the low-pass filter. However, with a slower sampling rate, a lower data rate is required.

A general communication system to transmit a sampled signal is shown in block diagram form in Figure 6.

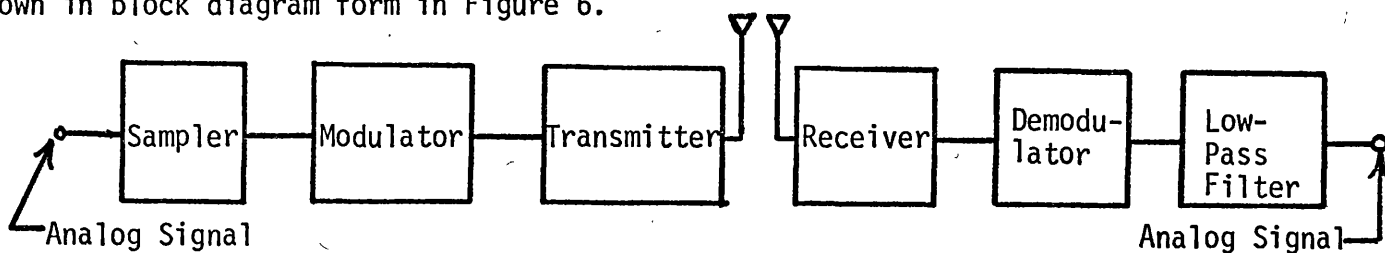


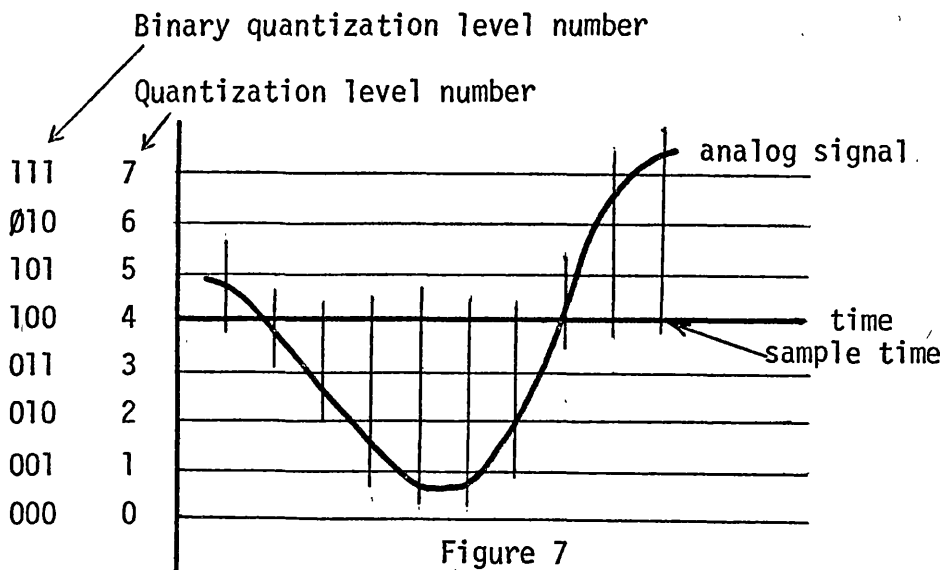
Figure 6

Sampled Signal Communication System

In the block diagram, the analog signal is sampled by the sampler which feeds the samples to the modulator. The modulator in turn generates either a pulse-amplitude modulation, a pulse-duration modulation, or a pulse-position modulation. The modulated signal is then transmitted. A distant receiver then detects the signal, a demodulator converts the signal to the original sampled pulses (plus noise due to the channel), and a low-pass filter converts the pulses to the original analog signal (plus noise). The relatively wide bandwidth requirements and poor noise performance of the above modulation schemes have generally limited their use. The modulation scheme that has emerged in general use is a pulse-code modulation where the samples are quantized, that is, only a finite number of levels are allowed for the samples. This process does add a noise, called quantization noise, to the signal; but now the quantization levels can be numbered and the number of the level transmitted instead of a pulse level. Usually, the number of the level is sent using a binary alphabet. Certain advantages are then realized such as the receiver decision function is simplified, because now its only decision is between a binary alphabet zero or a one versus a decision between an infinite number of levels with the unprocessed sample system. Then, too, digital processing of the data is possible and the message can be repeated with minimum effects due to noise. If repeater stations are spaced adequately close, a binary signal can be repeated many times with no degradation.

In Figure 7 is shown a segment of an analog signal which is to be sampled, quantized, and digitized for transmission over a binary communication channel. The segment of signal would be transmitted as a sequence of

binary numbers (e.g., 100, 100, 011, 010, 001, 010, 011, 100, 101, 110, where time runs from left to right).



Quantized Analog Signal

The electronic device which performs this function is called an analog-to-digital converter (A-D converter). A-D converters are made with different sampling rates (to accommodate different signal bandwidths), different number of quantization levels (usually in terms of 2^n levels where n is the number of binary symbols per level), and each A-D converter is made to accept a signal whose amplitude is limited between a lower and upper bound. Thus an A-D converter might accept an input signal whose voltage must range between plus and minus 1 volt, where 10,000 samples per second will be taken, and where 512 different quantization levels are permitted. Thus, in this case, the binary number for each quantization level would be represented by seven binary numbers.

The digital-to-analog (D-A) converter performs the reverse function of the A-D converter. For each binary number it receives, a voltage impulse is generated whose amplitude corresponds to the proper quantization level. Thus, a series of voltage samples are regained. These samples, as discussed earlier, can be used to generate the original signal by passing the samples through a proper low-pass filter. Somehow, the D-A converter has to know the binary number synchronization so that it knows which binary symbols represent which numbers in each digit. A pulse-code modulation communication (PCM) system block diagram is shown in Figure 8.

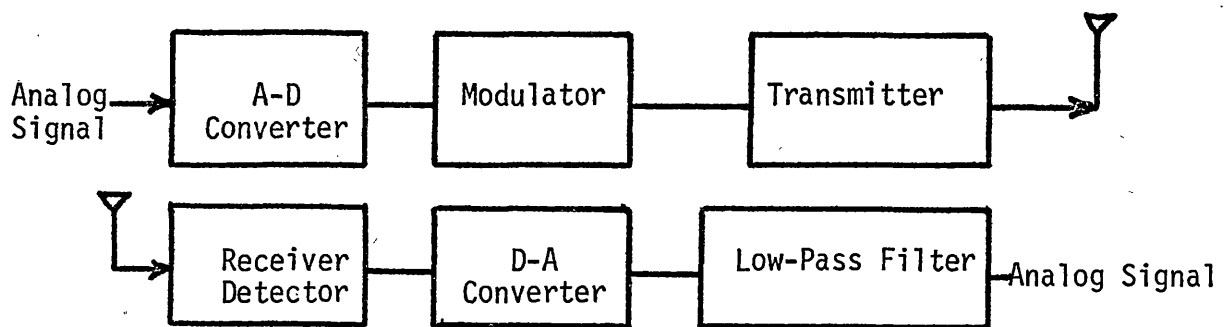


Figure 8

General PCM System

In the PCM system, the A-D converter includes a sampler and level numbering system. The digital modulator converts the binary symbols to a modulation such as phase-shift keying (PSK) or frequency-shift keying (FSK). The transmitter then amplifies the modulated signal and sends it on the channel. The receiver at the distant terminal processes the received signal so that the digital demodulator can recover the binary symbol from the signal. The D-A converter converts the numbered levels to the

appropriate sample voltage levels which are then passed through a low-pass filter to reconstruct the analog signal. The output analog signal will be delayed in time due to delays in encoding at the sending end, the propagation path time delay and delays at the receiving terminal. Such delays, in total, should not exceed a fraction of a second and are generally of no concern. The final analog signal will be corrupted not only by errors in the binary numbering system caused by channel noise, but also by the quantization noise which will corrupt the signal.

Pulse-code modulation systems are widely used for a variety of communication purposes ranging from telephone systems to space craft data recovery systems. PCM systems are readily available on the market and are proven and reliable. Most systems are able to handle data from more than one source (e.g., a system may handle 20 separate phone channels). The sampling arrangement is such that a sample is taken first from Channel 1, then Channel 2, then Channel 3, etc. The sampling rate has to be great enough to sample Channel 1 and all other channels at the proper rate. At the receiving terminal, proper decoding and synchronization must be accomplished to separate the signals. Such a system is called a time division multiplexed system. The PCM system must be matched to the requirements of the signals to be transmitted. In addition to the message signals that have to be transmitted, time synchronization data also have to be transmitted so that the decoding end can properly separate the channels.

Conversations with U. S. Forest Service personnel have indicated that no more than 16 gray scales have been identified on their IR scanner images. Further, no serious complaints as to the quality of the images have been heard. It seems reasonable that the Forest Service IR scanner analog signal could be quantized into 16 (corresponding to four binary digits per level number) or 32 (corresponding to five binary digits per level number) levels and then transmitted via a pulse-code modulation system. Mr. John Aspnes, a graduate student at Montana State University, has considered the quantization of an IR scanner signal. His report, which is in Appendix E, shows the degradation in signal-to-noise ratio when only four or five binary digits are used per sample. The degradation is also related to image quality.

2. Basic Digital Communication System

As one considers a digital communication system in place of an analog system there are specific system parameters which provide insight to digital system applicability. Several of the system parameters include sample rate, quantization levels, bit rate, and effective base-band signal bandwidth. Limitations are placed on these system parameters by state-of-the-art digital equipment, and thus a system design can be analyzed for implementation.

A basic digital system is shown in Figure 9.

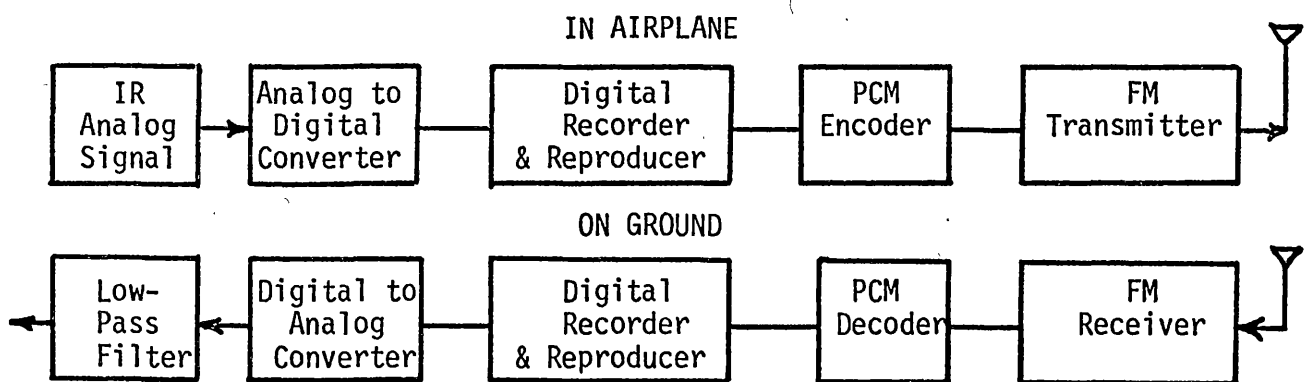


Figure 9

PCM System for IR Scanner Data

The infrared scanner signal is of two general types: one with a periodicity of 5 milliseconds and a base-band signal bandwidth of 208 kHz, and another with a periodicity of 10 milliseconds and a base-band signal bandwidth of 104 kHz. In order to effectively digitize and reassemble these analog signals, the signals must be sampled at a rate greater than twice the highest significant frequency in the infrared scanner bandwidth. This means that an analog-to-digital converter (A/D) must perform a minimum of 416,000 and 208,000 conversions per second on 208 kHz and 104 kHz bandwidth infrared signal, respectively. Off-the-shelf A/D converters can easily perform the desired sampling and conversion rates.

The first step in analyzing the digital recorder and reproducer in our system is to ask, "What do I want the digital recorder to record?" From the block diagram, the digital recorder is to record the output of the A/D converter. The A/D converter (208 kHz bandwidth input signal) is outputting 416,000 conversions per second with four binary data bits per conversion, for a total bit rate of 1.664 million bits per second. (It is suggested that since the ground visual display equipment (cathode ray tube and dry film equipment) can recognize approximately 16 gray scales, a binary string of four digits can effectively produce the required resolution. Additional binary digits can be added if the resolution proves inadequate, yet this will lead to an increased bit rate.) A study of conventional portable digital magnetic tape players and reproducers provides insight into the feasibility of the basic digital system.

The digital recorders' tape speed and bit packing density decide the maximum bit rate recordable. The top of the line portable digital tape recorders have maximum tape speeds of 30 inches per second and the associated magnetic tape can store a maximum of 1,600 binary digits per inch. Thus, this device can record a bit rate of $30 \times 1,600 = 48,000$ bits per second. One can easily see that the digital recorder is not feasible since it does not come close to the required recordable bit rate of 1.644 millions bits per second. In fact, the equivalent recordable analog bandwidth of the digital recorder is approximately 4,000 to 6,000 Hz.

Adjustments can be made to the basic digital system to reflect the constraints placed on the system by the digital recorder; note Figure 10.

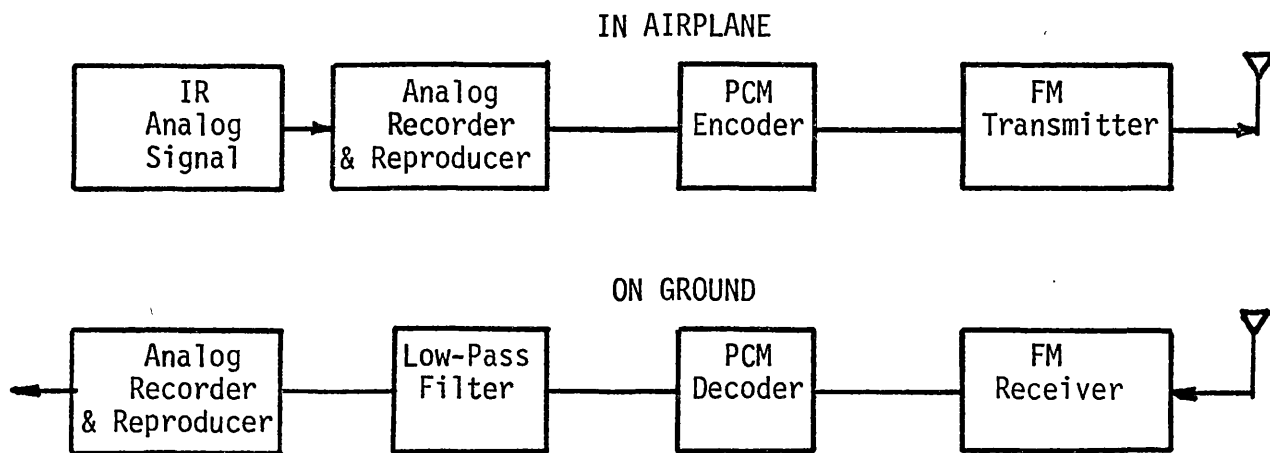


Figure 10

PCM System Using Analog Tape Recorders

An acceptable analog recorder (see Interim Report #3) now replaces both the A/D converter and the digital recorder and reproducer.

A pulse-code modulation (PCM) system is a digital encoding/decoding system which enables one to encode/decode signals to a high degree of accuracy (99.9%). Since only four binary digits are needed to provide adequate resolution, the degree of encoding accuracy drops significantly. Thus, with a four-bit digital system, one loses an important digital system advantage of encoding accuracy. Within the PCM encoder is an A/D converter, a synchronizing code generator, error checking code generator, and a digital multiplexer, all of which set the maximum bit rate from the device. The general state-of-the-art bit rate from a PCM encoder is approximately 1 million binary digits per second. Faster PCM encoders are available on developmental basis only. If 1 million binary digits per second is the maximum bit rate from the PCM system, again our required bit rate of 1.664 million bits per second for a base-band signal bandwidth of 208 kHz is beyond the performance limitations of a PCM system.

One might ask, "What is the effective base-band signal bandwidth encodable on a PCM system?" To answer this question, assume that the maximum bit rate from the PCM encoder is 1 million bits per second. Of these 1 million bits per second, about 80% are data bits and the other 20% are synchronizing bits. The 800,000 data bits are derived from four bits per sample of the analog signal. Thus, the sampling rate of the digital equipment is $800,000 \div 4 = 200,000$ samples per second. From previous analysis, it was stated that the sampling rate must be greater than twice the highest significant frequency in the infrared scanner bandwidth. In fact, in this system, one should have a sample rate of

at least three times the base-band signal bandwidth in order to allow a guard band for the final signal filtering by the low-pass filter (see Figure 5). If the sample rate is three times the base bandwidth, then dividing the sample rate by three yields, $200,000 \div 3 = 66.6 \text{ kHz}$, the effective analog signal bandwidth encodable by a PCM system. This suggests that for the real time signals of 208/104 kHz bandwidth, a PCM system is not practical. In order to apply a PCM system, the analog signal bandwidth must be limited to less than 66 kHz. In light of recent band limiting tests as witnessed by Dr. Norman Shyne, Montana State University, band limiting of the infrared scanner signal may be a feasible alternative for either the analog or digital communication systems.

The low-pass filter previously mentioned can be a Butterworth filter; a 6-pole variety is suggested. This filter provides at least 40 db of attenuation per octave and has maximally flat amplitude response. This filter was used in band limiting tests of the analog IR scanner signal and operated satisfactorily. The cut-off frequency for the filter is set by the maximum encodable base bandwidth of the analog signal.

With the low-pass filters entered into the digital communication system for band limiting purposes, the basic block diagram is shown in Figure 11.

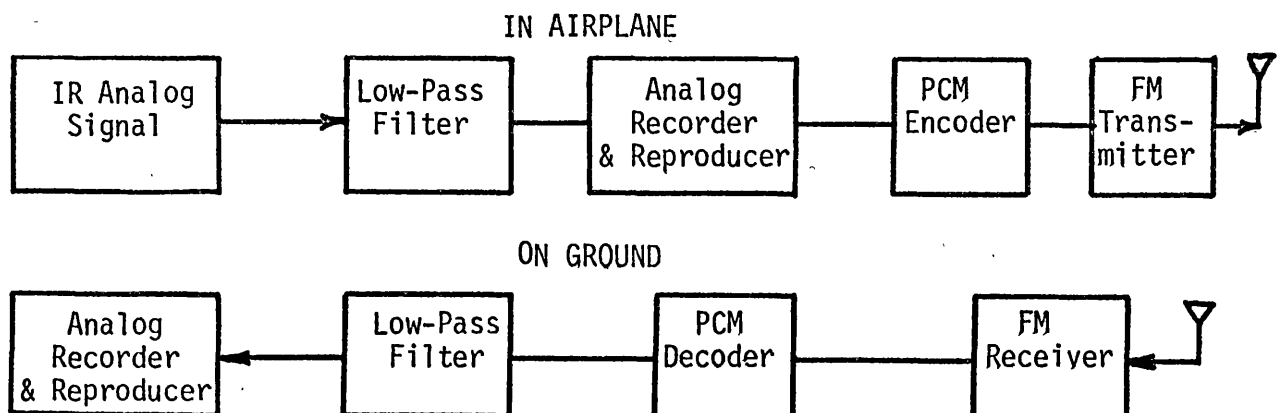


Figure 11

Bandwidth Limited PCM System for IR Scanner

An equipment list for the PCM equipment is included in Appendix B. PCM encoders, decoders, and low-pass filters are considered. The transmitters, receivers, and antennas used with the PCM system are the same FM units considered in the first part of this report. The bandwidth of the PCM signal which becomes the base-band input signal to the FM modulator (transmitter) has a bandwidth equal to 0.7 times the binary digit rate (bits/sec). If the receiving terminal has an output signal-to-noise ratio of approximately 13 db, the system can operate with a bit error rate of 10^{-7} .

3. Conclusions Pursuant to Basic Digital Communications Systems

State-of-the-art digital equipment presents severe limitations in the basic digital communication system for IR scanner data. A portable digital recorder and reproducer cannot record or reproduce a real time signal whose bandwidth is greater than 66 kHz. There are digital recorders which have sufficient speed and tape bit density, but these units are not portable and require restrictive environmental conditions. Analog recorders are not as severely limited and do provide an adequate means of recording and reproducing the desired signals. Therefore, the Emerson Analog Recorder, Model #R-540-0001 is recommended as the storage media from the infrared scanner on the airplane and as the output storage media to the visual display equipment on the ground.

A pulse code modulation system can be utilized in the proposed digital communication system configuration if the infrared scanner signal is band limited to 66 kHz. The benefit of accurate PCM encoding is not realized due to the limited four-digit binary code (16 gray scales). If one additional binary digit is added offering 32 gray scales and better

encoding accuracy, the infrared scanner signal must be band limited to approximately 55 kHz. Four- and five-bit digital PCM encoders are not available off-the-shelf, so the proposed application will require special engineering alteration of the device. With the PCM system, time compression or tape recorder speed-up is not permissible unless the infrared analog signal is further band limited. Also, the advantage of a PCM system relative to repeatability, such as when a telephone message is repeated many times while traversing the country, is not needed on the single air-to-ground link. The PCM system is an "over-kill" system which eats up costly bandwidth with synchronizing code bits and possible error correcting parity code bits which are used to aid requantizing at the decoder. The bandwidth of the digitally encoded signal (four-bit encoding and sampling rate of three times the base bandwidth) is at least 12 times the analog bandwidth, and for each additional digit, one must add three analog bandwidths. The constraints of the PCM system (bandwidth, bit rate, and cost) lead to the conclusion that under present digital equipment alternatives, the special equipment that would have to be designed and built make a PCM system for the 208/104 kHz scanner signal unfeasible. The PCM system can be considered only if the analog scanner signal is significantly band limited and then again the complexity, bandwidth, and cost may still prevent justifiable use of a PCM system.

APPENDIX A

This appendix contains what can best be described as an rf transmission system "catalog". A large number of carrier frequencies are shown (eight to be exact as shown in Table 1 of this report) and several base-band bandwidths are shown for each carrier frequency. The information includes make and model number of specific equipment, cost, technical specifications, and the calculated performance of each system. Notice that each system requires two pages; the first to list the equipment, the second to show the calculated performance.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 410-420 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D00100
Price: \$230

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620P
Price: \$3,100

Receiver:

Manufacturer: AACOM
Model Number: AR-400P
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$10,437

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz - 500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	115.1	123.1
Total System Gains (db):	55.0	
Total System Losses (db):*	116.7	125.0
Median Received Signal (dbm):*	-61.7	-70.0
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	37.3	29.0

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 410-420 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D00100
Price: \$230

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620P
Price: \$3,100

Receiver:

Manufacturer: AACOM
Model Number: AR-400P
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$10,437

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	115.1	123.1
Total System Gains (db):	55.0	
Total System Losses (db):*	116.7	125.0
Median Received Signal (dbm):*	-61.7	-70.0
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	34.7	26.0

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 410-420 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D00100
Price: \$230

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620P
Price: \$3,100

Receiver:

Manufacturer: AACOM
Model Number: AR-400P
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$10,437

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	115.1	123.1
Total System Gains (db):	55.0	
Total System Losses (db):*	116.7	125.0
Median Received Signal (dbm):*	-61.7	-70.0
Thermal Noise in Receiver (dbm):	-115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	32.3	24.0

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 410-420 MHz Baseband: 500 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D00100
Price: \$230

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620P
Price: \$3,100

Receiver:

Manufacturer: AACOM
Model Number: AR-400P
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$10,437

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	115.1	123.1
Total System Gains (db):	55.0	
Total System Losses (db):*	116.7	125.0
Median Received Signal (dbm):*	-61.7	-70.0
Thermal Noise in Receiver (dbm):	-111	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	90	
Fade Margin (db):*	28.3	20.0

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: Andrew Corporation
Type: 4 ft parabola
Model Number: P4-9C
Price: \$430

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,611

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	18.4	
Ground Antenna Beamwidth (deg):	19.5	
Ground Antenna VSWR:	1.3:1	
Ground Antenna Return Loss (db):	.05	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	121.8	129.9
Total System Gains (db):	64.4	
Total System Losses (db):*	122.9	131.0
Median Received Signal (dbm):*	-58.5	-66.6
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	40.5	32.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$14,281

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	121.8	129.9
Total System Gains (db):	55	
Total System Losses (db):*	123.4	131.5
Median Received Signal (dbm):*	-68.4	-76.5
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	30.6	22.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: Andrew Corporation
Type: 4 ft parabola
Model Number: P4-9C
Price: \$430

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,611

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	18.4	
Ground Antenna Beamwidth (deg):	19.5	
Ground Antenna VSWR:	1.3:1	
Ground Antenna Return Loss (db):	.05	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	121.8	129.9
Total System Gains (db):	64.4	
Total System Losses (db):*	122.9	131.0
Median Received Signal (dbm):*	-58.5	-66.6
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	37.5	29.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$14,281

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	121.8	129.9
Total System Gains (db):	55.0	
Total System Losses (db):*	123.4	131.5
Median Received Signal (dbm):*	-68.4	76.5
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	27.6	19.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: Andrew Corporation
Type: 4 ft parabola
Model Number: P4-9C
Price: \$430

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,611

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	18.4	
Ground Antenna Beamwidth (deg):	19.5	
Ground Antenna VSWR:	1.3:1	
Ground Antenna Return Loss (db):	.05	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	121.8	129.9
Total System Gains (db):	64.4	
Total System Losses (db):*	122.9	131.0
Median Received Signal (dbm):*	-58.5	-66.6
Thermal Noise in Receiver (dbm):	-115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	35.5	27.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$14,281

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	9	
Ground Antenna Beamwidth (deg):	45	
Ground Antenna VSWR:	2.0:1	
Ground Antenna Return Loss (db):	.5	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	40
Path Attenuation (db):*	121.8	127.9
Total System Gains (db):	55.0	
Total System Losses (db):*	123.4	129.54
Median Received Signal (dbm):*	-68.4	-74.5
Thermal Noise in Receiver (dbm):	-115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	25.6	19.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: Andrew Corporation
Type: 4 ft parabola
Model Number: P4-9C
Price: \$430

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L-V
Price: \$6,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$12,611

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-10 MHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	18.4	
Ground Antenna Beamwidth (deg):	19.5	
Ground Antenna VSWR:	1.3:1	
Ground Antenna Return Loss (db):	.05	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	121.8	129.9
Total System Gains (db):	64.4	
Total System Losses (db):*	123.0	131.0
Median Received Signal (dbm):*	-58.6	-66.6
Thermal Noise in Receiver (dbm):	-108	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-87	
Fade Margin (db):*	28.4	20.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: Pyramidal log periodic
Model Number: APN 106AA
Price: \$1,100

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L-V
Price: \$6,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,281

PATH DATA CALCULATIONS

Transmitter Power (watts):	20
Transmitter Power (dbm):	43
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	9
Ground Antenna Beamwidth (deg):	45
Ground Antenna VSWR:	2.0:1
Ground Antenna Return Loss (db):	.5
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	121.8
Total System Gains (db):	55
Total System Losses (db):*	123.4
Median Received Signal (dbm):*	-68.4
Thermal Noise in Receiver (dbm):	-108
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-87
Fade Margin (db):*	18.6

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 902-928 MHz Baseband: 4.5-6 MHz

Airborne Antenna

Manufacturer:	<u>Transco Products, Inc.</u>
Type:	<u>Quarter wave stub</u>
Model Number:	<u>P/N 11D28500</u>
Price:	<u>\$174</u>

Ground Antenna

Manufacturer:	<u>Andrew Corporation</u>
Type:	<u>4 ft parabola</u>
Model Number:	<u>P4-9C</u>
Price:	<u>\$430</u>

Transmitter

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AT-3620L-V</u>
Price:	<u>\$6,000</u>

Receiver:

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AR-400L-V</u>
Price:	<u>\$6,000</u>

Transmission Lines

Manufacturer:	<u>Andrew Corporation</u>
Type:	<u>50Ω foam dielectric coax cable</u>
Model Number:	<u>FSJ1-50</u>
Price:	<u>.68/ft</u>

Total Cost for Radio Equipment: \$12,611

PATH DATA CALCULATIONS

Transmitter Power (watts):	20
Transmitter Power (dbm):	43
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	18.4
Ground Antenna Beamwidth (deg):	19.5
Ground Antenna VSWR:	1.3:1
Ground Antenna Return Loss (db):	.05
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	121.8
Total System Gains (db):	64.4
Total System Losses (db):*	123.0
Median Received Signal (dbm):*	-58.6
Thermal Noise in Receiver (dbm):	-99
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-78
Fade Margin (db):*	19.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,350-1,400 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,755

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	10.9	
Ground Antenna Beamwidth (deg):	33.3	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	125.5	133.4
Total System Gains (db):	56.9	
Total System Losses (db):*	127.4	135.3
Median Received Signal (dbm):*	-70.5	-78.4
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	28.5	20.6

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,350-1,400 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer:	<u>Transco Products, Inc.</u>
Type:	<u>Quarter wave stub</u>
Model Number:	<u>P/N 11D28500</u>
Price:	<u>\$174</u>

Ground Antenna

Manufacturer:	<u>American Electronics Laboratories</u>
Type:	<u>18 in. parabola</u>
Model Number:	<u>APN 102C</u>
Price:	<u>\$575</u>

Transmitter

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AT-3620L</u>
Price:	<u>\$7,000</u>

Receiver:

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AR-400L</u>
Price:	<u>\$6,000</u>

Transmission Lines

Manufacturer:	<u>Andrew Corporation</u>
Type:	<u>50Ω foam dielectric coax cable</u>
Model Number:	<u>.68/ft</u>
Price:	<u></u>

Total Cost for Radio Equipment: \$13,755

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	10.9	
Ground Antenna Beamwidth (deg):	33.3	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	40
Path Attenuation (db):*	125.5	131.5
Total System Gains (db):	56.9	
Total System Losses (db):*	127.4	133.4
Median Received Signal (dbm):*	-70.5	-76.5
Thermal Noise in Receiver (dbm):	-117.0	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96.0	
Fade Margin (db):*	25.5	19.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,350-1,400 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,755

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	10.9	
Ground Antenna Beamwidth (deg):	33.3	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	30
Path Attenuation (db):*	125.5	129.0
Total System Gains (db):	56.9	
Total System Losses (db):*	127.4	130.9
Median Received Signal (dbm):*	-70.5	-74.0
Thermal Noise in Receiver (dbm):	-115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	23.5	20

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,350-1,400 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 3 ft parabola
Model Number: APN 110B
Price: \$850

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L-V
Price: \$6,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,031

PATH DATA CALCULATIONS

Transmitter Power (watts):	20
Transmitter Power (dbm):	43
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	16.9
Ground Antenna Beamwidth (deg):	16.6
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	125.5
Total System Gains (db):	62.9
Total System Losses (db):*	127.4
Median Received Signal (dbm):*	-64.5
Thermal Noise in Receiver (dbm):	-108
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-87
Fade Margin (db):*	22.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,350-1,400 MHz Baseband: 4.5-6 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 3 ft parabola
Model Number: APN 110B
Price: \$850

Transmitter

Manufacturer: AACOM
Model Number: AT-7240L-V
Price: \$10,500

Receiver:

Manufacturer: AACOM
Model Number: AR-400L-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$17,531

PATH DATA CALCULATIONS

Transmitter Power (watts):	40
Transmitter Power (dbm):	46
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	16.9
Ground Antenna Beamwidth (deg):	16.6
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	125.5
Total System Gains (db):	65.9
Total System Losses (db):*	127.4
Median Received Signal (dbm):*	-61.5
Thermal Noise in Receiver (dbm):	-99
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-78
Fade Margin (db):*	16.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,710-1,850 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,755

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	13.1	
Ground Antenna Beamwidth (deg):	26.0	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	127.7	135.7
Total System Gains (db):	59.1	
Total System Losses (db):*	129.6	137.6
Median Received Signal (dbm):*	-70.5	-78.5
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	28.5	20.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,710-1,850 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,755

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	13.1	
Ground Antenna Beamwidth (deg):	26	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	40
Path Attenuation (db):*	127.7	133.7
Total System Gains (db):	59.1	
Total System Losses (db):*	129.6	135.6
Median Received Signal (dbm):*	-70.5	-76.5
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	25.5	19.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,710-1,850 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,755

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	13.1	
Ground Antenna Beamwidth (deg):	26.0	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	30
Path Attenuation (db):*	127.7	131.2
Total System Gains (db):	59.1	
Total System Losses (db):*	129.6	133.1
Median Received Signal (dbm):*	-70.5	-74.0
Thermal Noise in Receiver (dbm):	115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	23.5	20.0

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,710-1,850 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 3 ft parabola
Model Number: APN 110B
Price: \$850

Transmitter

Manufacturer: AACOM
Model Number: AT-3620L-V
Price: \$6,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400L-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,031

PATH DATA CALCULATIONS

Transmitter Power (watts):	20
Transmitter Power (dbm):	43
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	19.1
Ground Antenna Beamwidth (deg):	13
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	127.7
Total System Gains (db):	65.1
Total System Losses (db):*	129.6
Median Received Signal (dbm):*	-64.5
Thermal Noise in Receiver (dbm):	-108
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-87
Fade Margin (db):*	22.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 1,710-1,850 MHz Baseband: 4.5-6 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$174

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 3 ft parabola
Model Number: APN 110B
Price: \$850

Transmitter

Manufacturer: AACOM
Model Number: AT-7240L-V
Price: \$10,500

Receiver:

Manufacturer: AACOM
Model Number: AR-400L-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$17,531

PATH DATA CALCULATIONS

Transmitter Power (watts):	40
Transmitter Power (dbm):	46
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	19.1
Ground Antenna Beamwidth (deg):	13.0
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	127.7
Total System Gains (db):	68.1
Total System Losses (db):*	129.6
Median Received Signal (dbm):*	-61.5
Thermal Noise in Receiver (dbm):	-99
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-78
Fade Margin (db):*	16.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,200-2,290 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 11D28500
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620S
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400S
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,707

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	14.8	
Ground Antenna Beamwidth (deg):	21.2	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	129.5	137.8
Total System Gains (db):	60.8	
Total System Losses (db):*	131.4	139.7
Median Received Signal (dbm):*	-70.6	-78.9
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	28.4	20.1

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,200-2,290 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620S
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400S
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,707

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	14.8	
Ground Antenna Beamwidth (deg):	21.2	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	40
Path Attenuation (db):*	129.5	135.8
Total System Gains (db):	60.8	
Total System Losses (db):*	131.4	137.7
Median Received Signal (dbm):*	-70.6	-76.9
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	25.4	19.1

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,200-2,290 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer:	<u>Transco Products, Inc.</u>
Type:	<u>Quarter wave stub</u>
Model Number:	<u>P/N 01-24-05340</u>
Price:	<u>\$125</u>

Ground Antenna

Manufacturer:	<u>American Electronics Laboratories</u>
Type:	<u>18 in. parabola</u>
Model Number:	<u>APN 102C</u>
Price:	<u>\$575</u>

Transmitter

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AT-3620S</u>
Price:	<u>\$7,000</u>

Receiver:

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AR-400S</u>
Price:	<u>\$6,000</u>

Transmission Lines

Manufacturer:	<u>Andrew Corporation</u>
Type:	<u>50Ω foam dielectric coax cable</u>
Model Number:	<u>FSJ1-50</u>
Price:	<u>.68/ft</u>

Total Cost for Radio Equipment: \$13,707

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	14.8	
Ground Antenna Beamwidth (deg):	21.2	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	30
Path Attenuation (db):*	129.5	133.3
Total System Gains (db):	60.8	
Total System Losses (db):*	131.4	135.2
Median Received Signal (dbm):*	-70.6	-74.4
Thermal Noise in Receiver (dbm):	-115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	23.4	19.6

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,200-2,290 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-7240S-V
Price: \$10,500

Receiver:

Manufacturer: AACOM
Model Number: AR-400S-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$17,207

PATH DATA CALCULATIONS

Transmitter Power (watts):	40
Transmitter Power (dbm):	46
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	14.8
Ground Antenna Beamwidth (deg):	21.2
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	129.5
Total System Gains (db):	63.8
Total System Losses (db):*	131.4
Median Received Signal (dbm):*	-67.6
Thermal Noise in Receiver (dbm):	-108
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-87
Fade Margin (db):*	19.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,200-2,290 MHz Baseband: 4.5-6 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 3 ft parabola
Model Number: APN 110B
Price: \$850

Transmitter

Manufacturer: AACOM
Model Number: AT-7240S-V
Price: \$10,500

Receiver:

Manufacturer: AACOM
Model Number: AR-400S-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$17,482

PATH DATA CALCULATIONS

Transmitter Power (watts):	40
Transmitter Power (dbm):	46
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	20.8
Ground Antenna Beamwidth (deg):	10.6
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	129.5
Total System Gains (db):	69.8
Total System Losses (db):*	131.4
Median Received Signal (dbm):*	-61.6
Thermal Noise in Receiver (dbm):	-99
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-78
Fade Margin (db):*	16.4

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,700-2,900 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620S
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400S
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,707

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	16.6	
Ground Antenna Beamwidth (deg):	17.3	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	50
Path Attenuation (db):*	131.5	139.9
Total System Gains (db):	62.6	
Total System Losses (db):*	133.4	141.8
Median Received Signal (dbm):*	-70.8	-79.2
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	28.2	19.8

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,700-2,900 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620S
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400S
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,707

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	16.6	
Ground Antenna Beamwidth (deg):	17.3	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	35
Path Attenuation (db):*	131.5	136.8
Total System Gains (db):	62.6	
Total System Losses (db):*	133.4	138.7
Median Received Signal (dbm):*	-70.8	-76.1
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	25.2	19.9

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,700-2,900 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: AACOM
Model Number: AT-3620S
Price: \$7,000

Receiver:

Manufacturer: AACOM
Model Number: AR-400S
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$13,707

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	10 Hz-500 kHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05	
Ground Antenna Gain (db):	16.6	
Ground Antenna Beamwidth (deg):	17.3	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	30
Path Attenuation (db):*	131.5	135.4
Total System Gains (db):	62.6	
Total System Losses (db):*	133.4	137.3
Median Received Signal (dbm):*	-70.8	-74.7
Thermal Noise in Receiver (dbm):	-115	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-94	
Fade Margin (db):*	23.2	19.3

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,700-2,900 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer:	<u>Transco Products, Inc.</u>
Type:	<u>Quarter wave stub</u>
Model Number:	<u>P/N 01-24-05340</u>
Price:	<u>\$125</u>

Ground Antenna

Manufacturer:	<u>American Electronics Laboratories</u>
Type:	<u>18 in. parabola</u>
Model Number:	<u>APN 102C</u>
Price:	<u>\$575</u>

Transmitter

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AT-7240S-V</u>
Price:	<u>\$10,500</u>

Receiver:

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AR-400S-V</u>
Price:	<u>\$6,000</u>

Transmission Lines

Manufacturer:	<u>Andrew Corporation</u>
Type:	<u>50Ω foam dielectric coax cable</u>
Model Number:	<u>FSJ1-50</u>
Price:	<u>.68/ft</u>

Total Cost for Radio Equipment: \$17,207

PATH DATA CALCULATIONS

Transmitter Power (watts):	40
Transmitter Power (dbm):	46
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	16.6
Ground Antenna Beamwidth (deg):	17.3
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	131.5
Total System Gains (db):	65.6
Total System Losses (db):*	133.4
Median Received Signal (dbm):*	-67.8
Thermal Noise in Receiver (dbm):	-108
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-87
Fade Margin (db):*	19.2

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 2,700-2,900 MHz Baseband: 4.5-6 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-24-05340
Price: \$125

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 3 ft parabola
Model Number: APN 110B
Price: \$850

Transmitter

Manufacturer: AACOM
Model Number: AT-7240S-V
Price: \$10,500

Receiver:

Manufacturer: AACOM
Model Number: AR-400S-V
Price: \$6,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$17,482

PATH DATA CALCULATIONS

Transmitter Power (watts):	40
Transmitter Power (dbm):	46
Frequency Response (Hz):	10 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.05
Ground Antenna Gain (db):	22.9
Ground Antenna Beamwidth (deg):	8.3
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.05
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	131.5
Total System Gains (db):	71.9
Total System Losses (db):*	133.4
Median Received Signal (dbm):*	-61.5
Thermal Noise in Receiver (dbm):	-99
Receiver Noise Figure (db):	9
Practical FM Threshold (dbm):	-78
Fade Margin (db):*	16.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 4,400-4,990 MHz Baseband: 50 kHz

Airborne Antenna

Manufacturer:	<u>Transco Products, Inc.</u>
Type:	<u>Quarter wave stub</u>
Model Number:	<u>P/N 01-24-05250</u>
Price:	<u>\$100</u>

Ground Antenna

Manufacturer:	<u>American Electronics Laboratories</u>
Type:	<u>3 ft parabola</u>
Model Number:	<u>APN 102C</u>
Price:	<u>\$575</u>

Transmitter

Manufacturer:	<u>CONIC Corporation</u>
Model Number:	<u>CTC-520-V</u>
Price:	<u>\$25,650</u>

Receiver:

Manufacturer:	<u>AACOM</u>
Model Number:	<u>AR-400C</u>
Price:	<u>\$7,000</u>

Transmission Lines

Manufacturer:	<u>Andrew Corporation</u>
Type:	<u>50Ω foam dielectric coax cable</u>
Model Number:	<u>FSJ1-50</u>
Price:	<u>.68/ft</u>

Total Cost for Radio Equipment: \$33,332

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	6 Hz-10 MHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.1	
Ground Antenna Gain (db):	20.8	
Ground Antenna Beamwidth (deg):	10.6	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.1	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	30
Path Attenuation (db):*	136.2	142.2
Total System Gains (db):	66.8	
Total System Losses (db):*	138.2	144.2
Median Received Signal (dbm):*	-71.4	-77.4
Thermal Noise in Receiver (dbm):	-120	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-99	
Fade Margin (db):*	27.6	21.6

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 4,400-4,990 MHz Baseband: 104 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-25-05250
Price: \$100

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: CONIC Corporation
Model Number: CTC-520-V
Price: \$25,650

Receiver:

Manufacturer: AACOM
Model Number: AR-400C
Price: \$7,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$33,332

PATH DATA CALCULATIONS

Transmitter Power (watts):	20	
Transmitter Power (dbm):	43	
Frequency Response (Hz):	6 Hz-10 MHz	
Airborne Antenna Gain (db):	3	
Airborne Antenna VSWR:	2.0:1	
Airborne Antenna Return Loss (db):	.5	
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.1	
Ground Antenna Gain (db):	20.8	
Ground Antenna Beamwidth (deg):	10.6	
Ground Antenna VSWR:	2.5:1	
Ground Antenna Return Loss (db):	.8	
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.1	
Protection Device Loss (db):	.5	
Path Length (miles):*	20	30
Path Attenuation (db):*	136.2	142.2
Total System Gains (db):	66.8	
Total System Losses (db):*	138.2	144.4
Median Received Signal (dbm):*	-71.4	-77.4
Thermal Noise in Receiver (dbm):	-117	
Receiver Noise Figure (db):	8	
Practical FM Threshold (dbm):	-96	
Fade Margin (db):*	24.6	18.6

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 4,400-4,990 MHz Baseband: 208 kHz

Airborne Antenna

Manufacturer: Transco Products, Inc.

Type: Quarter wave stub

Model Number: P/N 01-25-05250

Price: \$100

Ground Antenna

Manufacturer: American Electronics Laboratories

Type: 18 in. parabola

Model Number: APN 102C

Price: \$575

Transmitter

Manufacturer: CONIC Corporation

Model Number: CTC-520-V

Price: \$25,650

Receiver:

Manufacturer: AACOM

Model Number: AR-400C

Price: \$7,000

Transmission Lines

Manufacturer: Andrew Corporation

Type: 50 Ω foam dielectric coax cable

Model Number: FSJ1-50

Price: .68/ft

Total Cost for Radio Equipment: \$33,332

PATH DATA CALCULATIONS

Transmitter Power (watts):	20
Transmitter Power (dbm):	43
Frequency Response (Hz):	6 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.1
Ground Antenna Gain (db):	20.8
Ground Antenna Beamwidth (deg):	10.6
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.1
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	136.2
Total System Gains (db):	66.8
Total System Losses (db):*	138.2
Median Received Signal (dbm):*	-71.4
Thermal Noise in Receiver (dbm):	-115
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-94
Fade Margin (db):*	22.6

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 4400 - 4990 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products Inc.
Type: Quarter wave stub
Model Number: PIV 01-25-05350
Price: \$100

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: CONIC Corporation
Model Number: CTC-520V
Price: \$25,650

Receiver

Manufacturer: AACOM
Model Number: AR-400C-V
Price: \$7000

Transmission Lines

Manufacturer: Andrews Corporation
Type: 50 Ω foam dielectric co-ax cable
Model number: FST1-50
Price: .68 / ft.

Total Cost for Radio Equipment: \$33,332

RADIO TRANSMISSION EQUIPMENT

Carrier Frequency: 4,400-4,990 MHz Baseband: 1 MHz

Airborne Antenna

Manufacturer: Transco Products, Inc.
Type: Quarter wave stub
Model Number: P/N 01-25-05250
Price: \$100

Ground Antenna

Manufacturer: American Electronics Laboratories
Type: 18 in. parabola
Model Number: APN 102C
Price: \$575

Transmitter

Manufacturer: CONIC Corporation
Model Number: CTC-520-V
Price: \$25,650

Receiver:

Manufacturer: AACOM
Model Number: AR-400C-V
Price: \$7,000

Transmission Lines

Manufacturer: Andrew Corporation
Type: 50 Ω foam dielectric coax cable
Model Number: FSJ1-50
Price: .68/ft

Total Cost for Radio Equipment: \$33,332

PATH DATA CALCULATIONS

Transmitter Power (watts):	20
Transmitter Power (dbm):	43
Frequency Response (Hz):	6 Hz-10 MHz
Airborne Antenna Gain (db):	3
Airborne Antenna VSWR:	2.0:1
Airborne Antenna Return Loss (db):	.5
Line Loss Between Tx and Antenna (db): (5 feet of coax cable)	.1
Ground Antenna Gain (db):	20.8
Ground Antenna Beamwidth (deg):	10.6
Ground Antenna VSWR:	2.5:1
Ground Antenna Return Loss (db):	.8
Line Loss Between Rx and Antenna (db): (5 feet of coax cable)	.1
Protection Device Loss (db):	.5
Path Length (miles):*	20
Path Attenuation (db):*	136.2
Total System Gains (db):	66.8
Total System Losses (db):*	138.2
Median Received Signal (dbm):*	-71.4
Thermal Noise in Receiver (dbm):	-108
Receiver Noise Figure (db):	8
Practical FM Threshold (dbm):	-87.0
Fade Margin (db):*	15.5

*First figure is for a path length of 20 miles and the second figure is for a path length greater than 20 miles.

APPENDIX B

PCM EQUIPMENT LIST

<u>Device</u>	<u>Manufacturer</u>	<u>Model No.</u>	<u>Delivery</u>	<u>Comments</u>	<u>Cost</u>
PCM Encoder (must be modified for four binary digit words)	AACOM	PCM 5-60 (modified)	90-120 days	1 M bit rate	\$5,000.00
	IED Conic Corp.	PCM 410 (not modified)	90-120 days	1 M bit rate programmable	\$2,500.00
PCM Decoder	AACOM	PCM 15-6 (modified)	90-120 days	1 M bit rate	\$8,000.00
	IED Conic Corp.	DEC 370 (not modified)	90-120 days	1 M bit rate	\$3,500.00
Low-Pass Filter	Krohn-Hite	3341	50-60 days	High-pass - low-pass Freq. range: .01 Hz-100 kHz Attenuation: 48 db/octave *battery option (add \$100)	\$1,075.00

APPENDIX C

Interim Report #2 forms this appendix. It is included as part of this report to simplify the final report and also to make it easier to refer back to the results obtained as the work progressed.

INFRARED IMAGE TRANSMISSION STUDY

INTERIM REPORT #2

I. INTRODUCTION

This report is the second interim report for Supplement 25 to 12-11-204-12. The report covers the period from 1 July 1974 through 30 October 1974. The contract called for a report to be submitted on 1 October 1974. It was mutually agreed between the project manager for the Forest Service, Mr. Forest Madden, and the principal investigator for MSU, Dr. Bruce McLeod, that it would be more efficient to submit the second report at the end of October rather than the first.

II. PROBLEM DEFINITION

One of the areas to be looked at in the course of the work was to put down as specifically as possible a definition of the problem to be examined on this contract. This is not a simple task due to the fact that the overall system concept is quite complex and the concept changes with time due to new information. During the past month, several meetings were held between personnel involved on this contract and Dr. Norm Shyne to help define just what kind of a signal (or signals) is to be sent from the aircraft to the ground station. This signal could be in any of the following forms:

1. Raw data from the IR sensor
2. Raw data corrected for aircraft roll
3. Stored IR imagery
4. IR imagery stored in the form of TV frames

It appears, at this point in the work, that the transmission system should transmit a single signal from the aircraft to the ground station. The signal could be in several forms (TV frame, sampled data, etc.) but all processing on the signal would have been done on-board the aircraft. The ground station is viewed as simply receiving and using the information, but not processing it to correct for aircraft roll or color slicing to enhance the data, etc. The major reason for this is to keep the ground station and the transmission-receiver system as simple as possible.

III. PROGRESS ON THE RF TRANSMISSION SYSTEM

The work has concentrated in two areas. The first is that of defining some broad system specifications for use in contacting manufacturers. Also, such specifications are needed to begin trying to locate an acceptable frequency allocation. The second area considered was that of definitizing the relationship between some of the system parameters such as transmitter power level, receiver sensitivity, antenna gains, and the maximum distance or frequency that could be used.

The work in the first area has yielded the following broad transmission system specifications:

1. The radio system will use SSB-FM modulation.
2. Operation is being considered in the following frequency bands which have been allocated for Federal government use:
 - a. 902-928 MHz
 - b. 1427-1435 MHz
 - c. 1660-1850 MHz
 - d. 2700-2900 MHz
 - e. 5650-5925 MHz
 - f. 7125-8400 MHz
 - g. 10.68-10.70 GHz

3. The system bandwidths being considered include:
 - a. 104 KHz
 - b. 208 KHz
 - c. 4.5-6 MHz
4. The transmitter will have +30 to +43 dbm power output.
5. The receiver will have a minimum sensitivity of about -80 dbm.
6. Antenna specifications have not been definitized, however, circular polarization is being given serious consideration.

Letters have been sent to about 60 antenna and radio equipment manufacturers to determine what is available within the above broad specifications. A lengthy phone conversation was held with Mr. Bill Morton at the Forest Service Electronics Center in Beltsville, MD, to get some information on IRAC requirements. He suggested the above frequency ranges, but stated there is no "open area." A shared frequency based on noninterference is the best available according to Mr. Morton. He felt that to proceed, a set of fairly definite system specifications would have to be submitted to IRAC and they would eventually rule on an operating frequency and bandwidth. Work will proceed along this line.

In the second area of trade-offs between the system parameters, the work has yielded the results shown in Figure 1 and Figure 2. These figures show the maximum frequency that can be used for a given maximum range (or given a frequency the figures show the maximum distance). They are based on the following analysis.

The transmission system in a general block diagram form is shown in Figure 3.

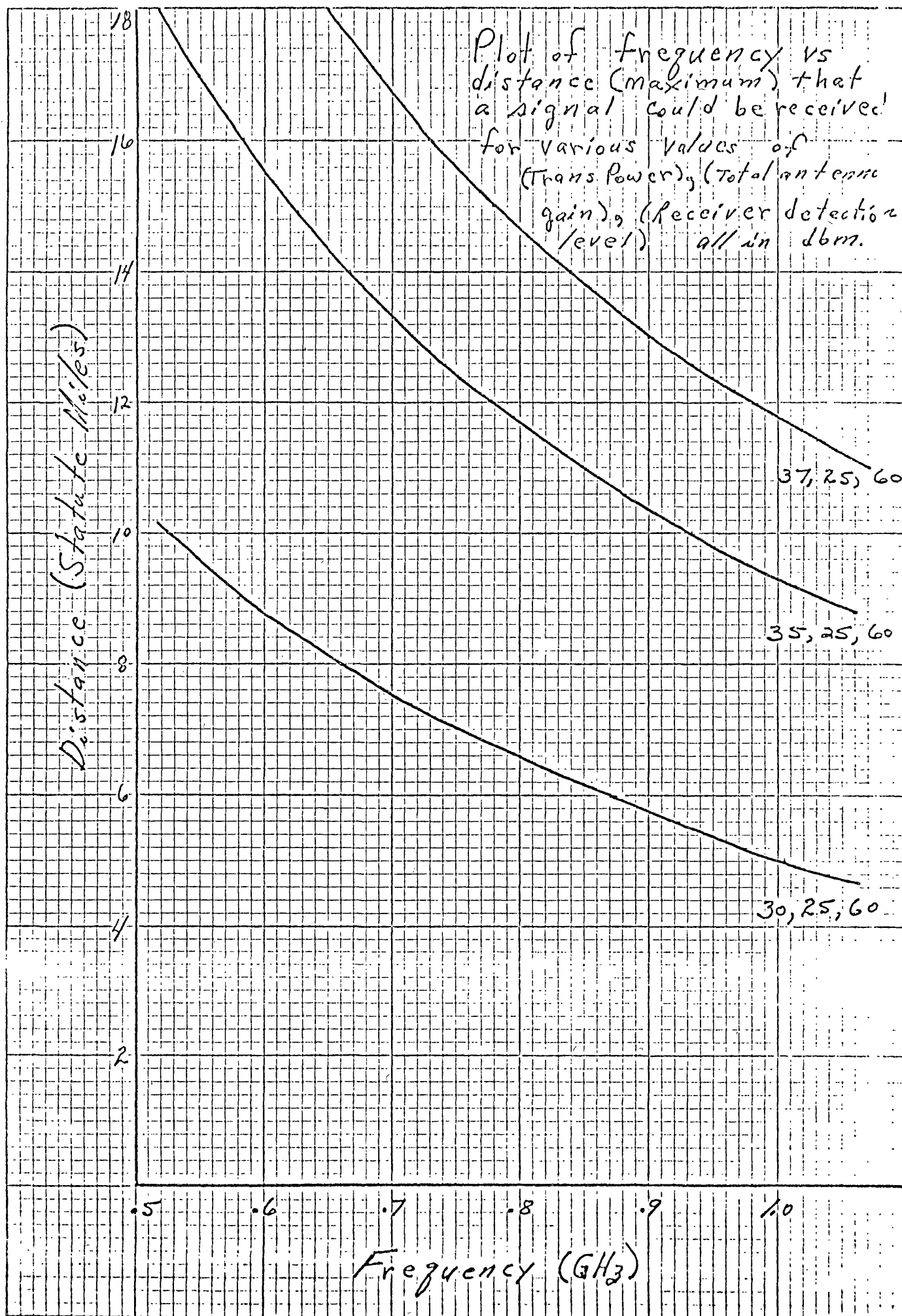
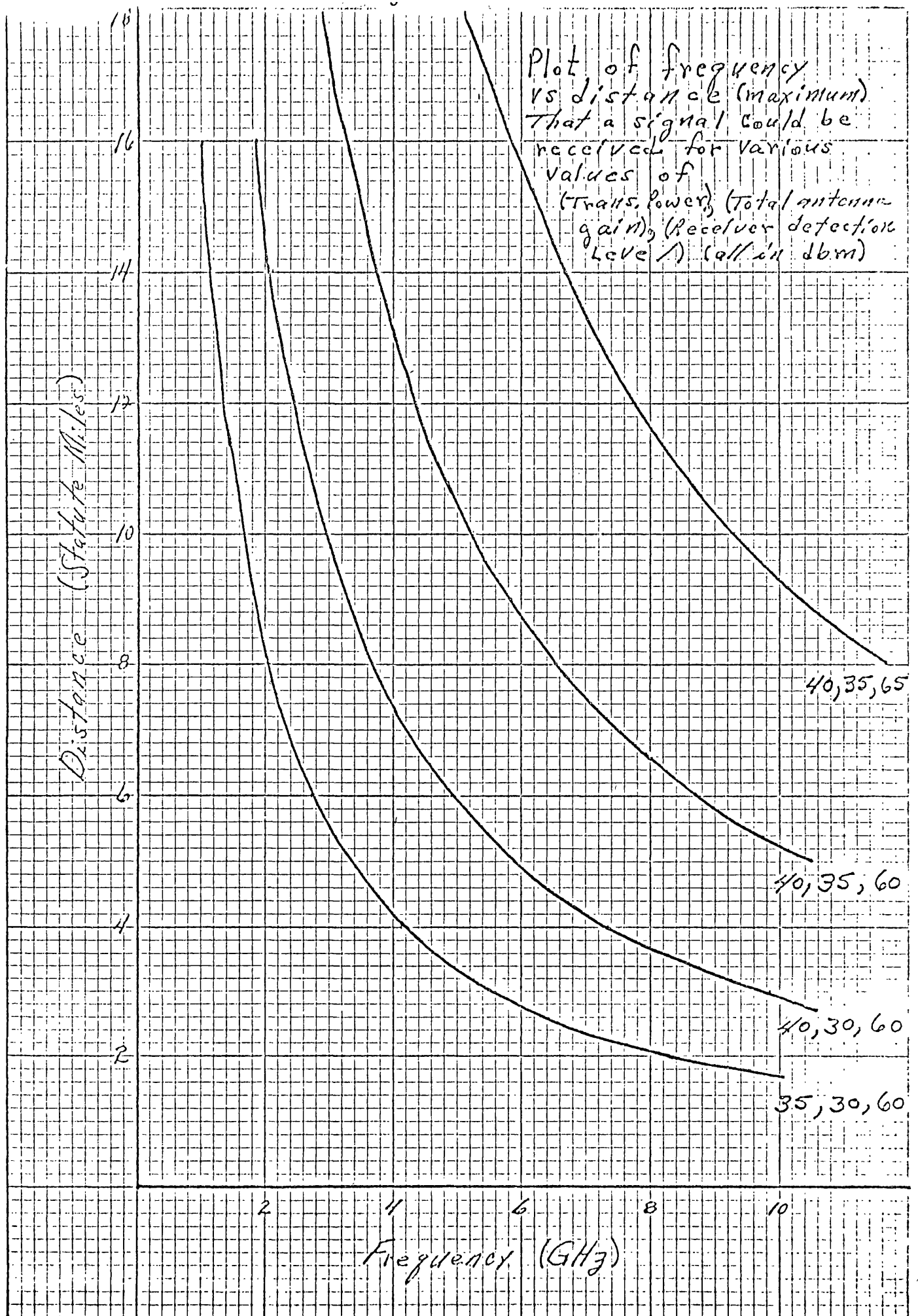


Figure 1



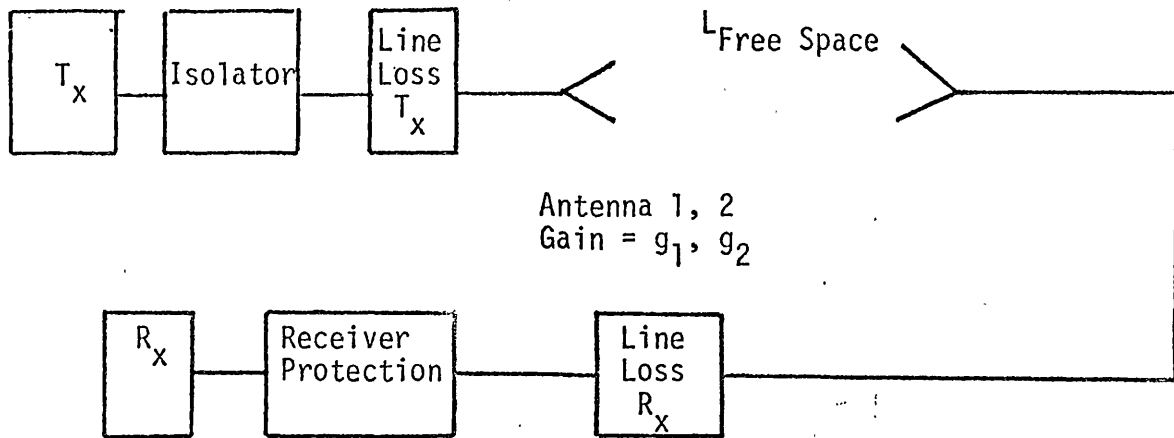


Figure 3
System Block Diagram

The power budget equation (in dbm) is:

$$T_x - L_{fs} - L_I - L_T + (g_1 + g_2) - L_R - L_{RP} = R_x \quad (1)$$

where,

T_x = transmitted power level (dbm)

R_x = minimum receiver power level

L_I = isolator loss

L_T = transmission line loss

L_R = receiver line loss

$g_1 + g_2$ = total antenna gain

L_{fs} = free space loss

It is estimated that all the internal losses (L_T , L_R , L_I , L_{RP}) will not exceed 4 db. Therefore, the equation can be written as:

$$L_{fs} = T_x - R_x + (g_1 + g_2) - 4 \quad (2)$$

The expression for free space loss is:

$$L_{fs} = 96.6 + 20 \log f + 20 \log d \quad (3)$$

where,

f = frequency in GHz

d = distance in statute miles

If (3) is rewritten slightly,

$$L_{fs} = 96.6 + 20 \log fd \quad (4)$$

and then (2) is used, one can write,

$$\log fd = \left[\frac{1}{20} \{ T_x - R_x - 4 + (g_1 + g_2) \} - 96.6 \right] \quad (5)$$

$$\text{Now let } \epsilon_p = T_x - R_x + (g_1 + g_2) \quad (6)$$

$$\text{So } f = \frac{10^{\frac{(\epsilon_p - 100.6)}{20}}}{d} \quad (7)$$

The graphs shown in Figure 1 and Figure 2 are based on Equation (7) for various "reasonable" values of ϵ_p . For instance, the transmitter will probably be in the 1- to 20-watt range ($T_x = +30$ to $+43$ dbm), the receiver will probably have a minimum detectable power level of about -80 dbm ($R_x = -80$ + a 20-dbm fade margin = -60 dbm), and the total antenna gain will probably be 30 to 35 db above a dipole ($g_1 + g_2 \simeq 30$ to 35 dbm). The figures show a wide range of transmitter power and antenna gain since these two parameters are perhaps the easiest to select over a wide range.

It is seen from the figures that if transmitter power and antenna gain are to be minimized while a maximum transmission distance is maintained, one should choose as low an operating frequency as possible. However, a criteria that is not shown on the figures is the "interference potential." This factor decreases with increasing frequency in most cases.

These graphs will be put to use as the system specifications become more definitized. They will also be used to evaluate overall system performance for various combinations of gear as the replies come back in from the various manufacturers contacted.

IV. PROGRESS ON SYSTEM OPERATION DEFINITION

The effort under this heading has been directed toward the consideration of the aircraft flight plan, the bandwidth required for transmitting the information and the gain and pattern of the two system antennas. The next few paragraphs relate the work done on the interconnection of these three system parameters.

In the contact with Mr. Morton, the area of system bandwidth was discussed. He indicated that IRAC would most probably look with favor on the narrowest possible bandwidth for the system to comply with their "conserve spectrum" concept. The implication was that a narrow bandwidth would mean less interference potential from the IR transmission system. That is not necessarily true. The interference potential of the system is a function of aircraft altitude, transmitted power, antenna gain and pattern, transmitter frequency, and location of the ground station. All of the above are perhaps obvious, but not so obvious is another important factor, the length of time of the transmission from the aircraft. To illustrate this point, suppose the IR transmission system used a 6-MHz bandwidth and transmitted a complete image of a 1-mile square area in 1 second. The rf signal might interfere with another station, but a 1-second interruption would probably go without notice. Thus, consideration must be given to the time of transmission as well as all the other factors.

Of course, the time of transmission also bears on the aircraft flight pattern, the antenna patterns, and the required system gain. The discussions during the past month have centered around the possibility of using a semifixed ground antenna instead of a manually or automatically steerable antenna. A semi-fixed antenna would be aligned with the aircraft at the start of an information transfer and then not moved again. If this were the system used, the ground station antenna would be a fairly low gain, but broad beam-width antenna while the airborne antenna would be a high gain, directive antenna. As is illustrated by Figure 1 and Figure 2, it is the sum of antenna gains that is important and hence, a trade-off is available as to which antenna is high or low gain. Note that the faster the information can be transferred to the ground, the smaller the need for steering the general antenna.

V. SUMMARY

In summary, the work has progressed in several areas. Manufacturers of available gear have been contacted by letter to get their latest equipment information. A graphical technique has been developed to allow rapid evaluation of possible system specifications and specific equipment performance within the system. Very general system specifications have been set forth to be modified as more information is developed. Trade-off areas have been identified in the definition of the system concept which will be examined now to begin to develop the optimum system.

VI. WORK FOR THE NEXT PERIOD

A major effort will be made to define a possible system for the next report along with supporting reasons. This would be a definite point of departure for discussion between NFFL personnel and MSU personnel to develop the final system concept.

The responses are starting to come in from the manufacturers and a major portion of the effort will be to examine and evaluate equipment specifications. It is anticipated that antennas and the transmitter will be identified by the next report.

APPENDIX D

Interim Report #3 forms this appendix. There were some significant results, recommendations, and figures in this report. To avoid putting them in the body of the final report and discussing them again, Report #3 is contained herein for reference.

INFRARED IMAGE TRANSMISSION STUDY

Interim Report #3
February 1975

I. INTRODUCTION

This report is the third interim report for Supplement 25 to 12-11-204-12. The report covers the period from 1 November 1974 through 1 February 1975.

II. PROJECT MEETING

On 10 December 1974, a project meeting was held between Forest Madden and Dr. Bruce McLeod and Dr. Dan March to discuss progress on the transmission study. After discussing the system parameters that were beginning to emerge in the ERL study, a summary session was held in which several system parameters were mutually agreed upon. These appear below:

1. Maximum range - 20 miles
2. Maximum altitude - 12,000 feet
3. Plane velocity - 150 knots min., 180 k nominal and 250 k maximum
4. The signal sent to the ground will be a single $f(t)$ with all information, corrections, etc., done before it is delivered to the terminals of the down-link transmitter.
5. A tone signal is necessary for ground station antenna steering and alignment.
6. The design will include at least a 20-db fade margin.
7. Antenna position on aircraft will be recommended by ERL engineers.
8. Bandwidth to be considered will include at least 104 Hz, 208 KHz, 50 KHz, and 4.5 MHz.

The balance of the meeting was used to discuss and clarify, where possible, the mission of the system, system philosophy, and the kind of information that will be needed at the ground station.

A. Technical Progress

The effort is proceeding along two basic paths as discussed in the previous reports. Dr. McLeod and his graduate student, Mr. George Wheatcroft, are working on the radio frequency (rf) transmission problem (including finding the necessary gear) while Dr. Dan March and his graduate student, Mr. Dale Davidson, are working on the signal processing problem. These areas will be discussed below in separate sections.

1. Radio Frequency Transmission

After the meeting in December which established system parameters such as maximum distance and altitude, work proceeded to identify such things as antenna gains, transmitter power, antenna patterns, and receiver sensitivity. Consider first the antennas.

As was discussed in the last report, it is the sum of the antenna gains in db that appears in the system power budget. For clarity, several of the needed equations are stated below:

$$L_{fs} = 96.6 + 20 \log f_{\text{GHz}} d_{\text{mi}} \quad (1)$$

$$T_x - L_s - L_{fs} + (G_p + G_g) = R_x \text{ min.} \quad (2)$$

where L_{fs} = free space loss

f_{GHz} = transmitter frequency in GHz

d_{mi} = distance in miles from the transmitting to receiving antennas

L_s = the sum of all the system losses

$G_p + G_g$ = the gain of the antenna on the plane plus the gain of the ground station antenna

T_x = transmitter power in dbm

$R_{x \text{ min.}}$ = minimum signal the receiver can use in dbm

It is our conclusion at this time that the sum of the antenna gains will have to be between 20 db and 30 db to achieve the necessary distance and simultaneously provide an adequate system fade margin.

Since the airborne antenna must not alter the aerodynamic capability of the aircraft to any great extent, G_p will have a value of $0 < G_p < 4$ db. This means the ground antenna must have a gain in the area of 20 db. To get such a gain, one must consider a parabolic dish.

Consider then, a parabolic dish whose gain and beamwidth are given by:

$$\text{Beam angle } \theta \approx \frac{70}{f_{\text{GHz}}(D_{\text{ft}})} = \frac{7 \times 10^4}{f_{\text{MHz}}(D_{\text{ft}})} \quad (3)$$

$$G_g = 20 \log f_{\text{GHz}} + 20 \log D_{\text{ft}} + 7.4 \quad (4)$$

where θ = beam angle at the 3 db points

f_{GHz} = frequency in gigahertz

D_{ft} = diameter of dish in feet

Equations (1), (2), and (4) may be combined to yield a simple equation for the necessary dish size. Table 1 shows the system parameters as they stand at this time:

TABLE 1

Transmitter power - 20 watts	=	+43 dbm
Minimum usable receiver signal level	=	-80 dbm
Desired fade margin	=	+20 dbm
$R_{x \text{ min}}$	=	-60 dbm
Maximum transmission distance	=	20 miles
The sum of all system losses	=	$2 < L_s < 4 \text{ dbm}$
Airborne antenna gain	=	$0 < G_p < 4 \text{ dbm}$

Using Table 1 and Equation (1), one has:

$$L_{fs} = 122.62 + 20 \log f_{\text{GHz}} \quad (5)$$

Equation (2) may be written as:

$$G_p + G_g = 19.62 + 20 \log f_{\text{GHz}} + L_s \quad (6)$$

by using Table 1 and Equation (5). Now if Equation (4) is used in Equation (6) to eliminate G_g , one has:

$$20 \log D_{ft} = 12.22 - G_p + L_s \quad (7)$$

The largest dish diameter would occur for the minimum G_p and the maximum system loss (i.e., $G_p = 0$; $L_s = 4$). Thus, the maximum dish size would be:

$$20 \log D_{ft} = 12.22 - 0 + 4 = 16.44 \quad (8)$$

or

$$D_{ft} = 6.47 \text{ feet}$$

The smallest dish size that would meet the system specifications of Table 1 would occur for $G_p = 4 \text{ dbm}$, $L_s = 2 \text{ dbm}$.

Then,

$$20 \log D_{ft} = 12.22 - 4 + 2 = 10.22 \quad (9)$$

or

$$D_{ft} = 3.24 \text{ feet}$$

Notice in Equation (7) that frequency does not appear explicitly. This occurs because as frequency goes up, free space loss increases [See Equation (5).], but also as frequency increases, the dish antenna gain goes up at the same rate [See Equation (4).], and hence, the two cancel each other. Therefore, dish sizes found from Equation (7) are the sizes needed to meet the system specifications of Table 1 independent of the operating frequency choice.

It should also be pointed out that a seemingly small change in receiver sensitivity has a significant effect on the dish antenna size. Suppose, for instance, a receiver was used with a -83 dbm minimum signal level instead of -80 dbm. The result of this (still assuming a 20-db fade margin) in Equation (7) is:

$$20 \log D_{ft} = 9.22 - G_p + L_s \quad (10)$$

For the two cases used in Equations (8) and (9), one now has:

$$4.58 \text{ ft.} \geq D_{ft} \geq 2.3 \text{ ft.} \quad (11)$$

Also, note it also works the other way. The minimum sensitivity of the receiver is a very important specification.

A second specification of the antennas is their beamwidth. The beamwidth of the parabolic dish is given by Equation (3). For the sake of simplicity, the beamwidth will be calibrated for the same cases used to obtain the antenna diameters (D_{ft}) of Equations (8), (9), and (11). Thus, one has:

TABLE 2

<u>System Loss (L_s)</u>	<u>Airborne Antenna Gain G_p</u>	<u>D_{ft}</u>	<u>Frequency</u>	<u>θ</u>
4 db	0 db	6.47 ft.	915 MHz	11.82°
2 db	4 db	3.24 ft.	915 MHz	23.61°
4 db	0 db	6.47 ft.	2 GHz	5.41°
2 db	4 db	3.24 ft.	2 GHz	10.8°

Consider now the figure shown below:

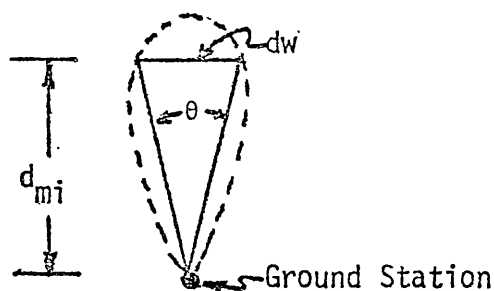


Figure 1

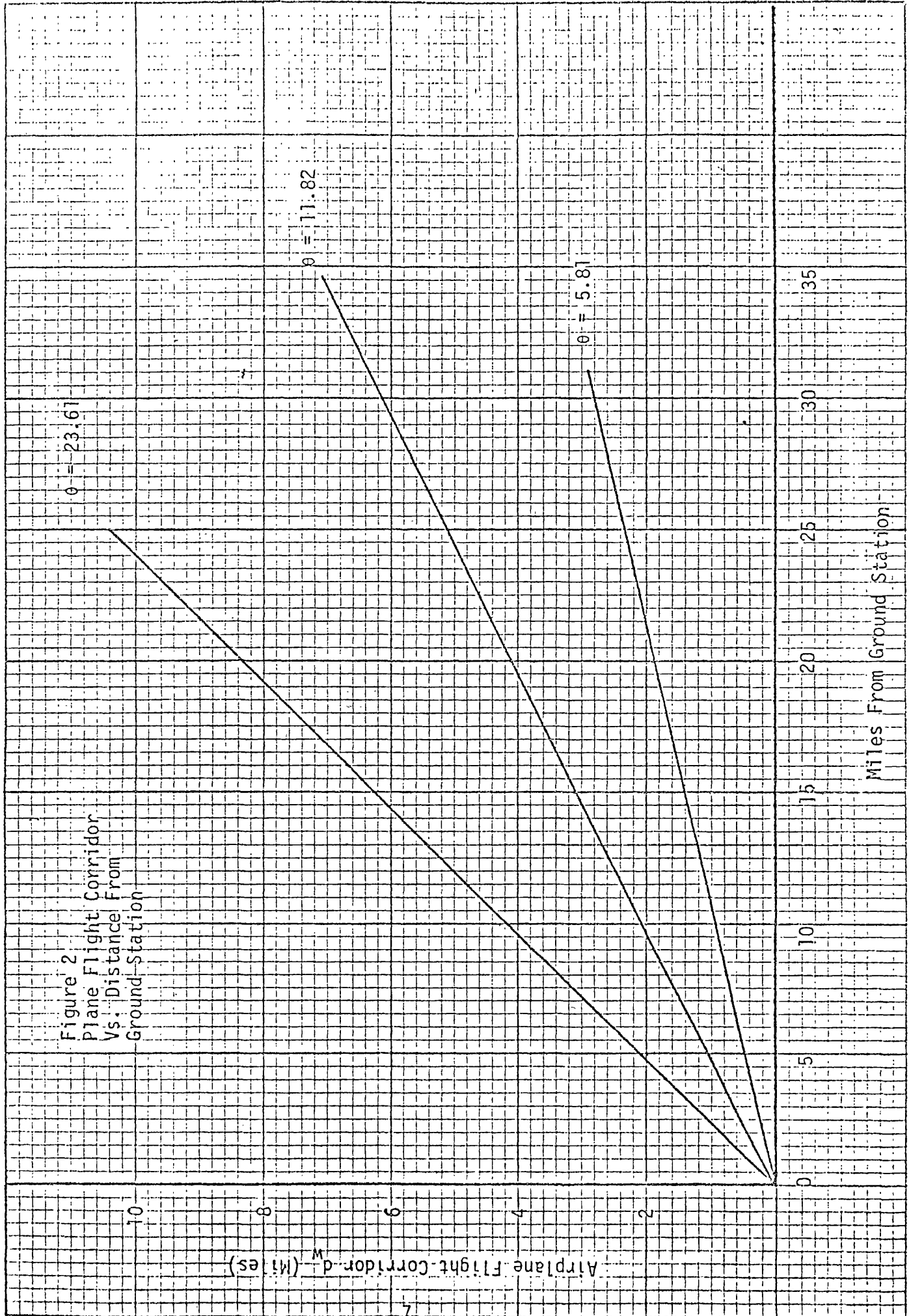
Antenna Beam Pattern

To calculate the distance (dw), one simply writes:

$$dw = 2 d_{mi} \tan\left(\frac{\theta}{2}\right) \quad (12)$$

where dw is the width of the flight corridor of the plane to stay in the main beam of the antenna. A plot of Equation (12) is shown in Figure 2 for several beamwidth angles. It would appear from the figure that the plane should not come much closer than about 4 miles of the ground station to avoid "tracking maneuvers" with the ground antenna.

The flight pattern suggested by this analysis is sketched in Figure 3.



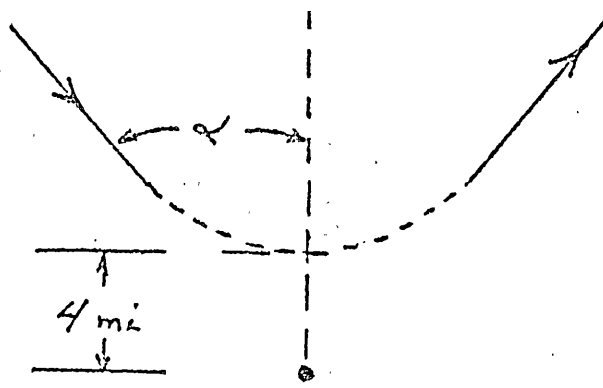


Figure 3

Suggested Flight Pattern

The plane could be directed to fly a straight line path α° off of some reference line (like true north or west, etc.) for a period of 5 minutes at 167 knots, then to make a left turn of β° and fly a straight line for another 5 minutes. It would be convenient for the pilot if the ground station simply gave him a compass heading in and a left turn to a second heading out. The 5 minutes and the 167 knots speed were suggested since at 167 knots, it takes 5 minutes for the plane to go from 20 miles out to within 4 miles of the ground station. Thus, if necessary, a 10-minute transmission period is available (5 minutes on each leg).

2. Airborne Antenna

The antenna being proposed for use on the aircraft is a Transco P/N 11D28500 which has the following specifications:

- a. Frequencies from 500 to 2,000 MHz
- b. Vertical polarization
- c. Gain = 3.5 db over isotropic radiator
- d. VSWR < 3.0
- e. Pattern is that of quarter-wave monopole over a ground plane

The radiation of a quarter-wave monopole depends upon the configuration of the ground plane. For a ground plane of infinite radius, the pattern would look like the lower half of the radiation pattern for a half-wave dipole.

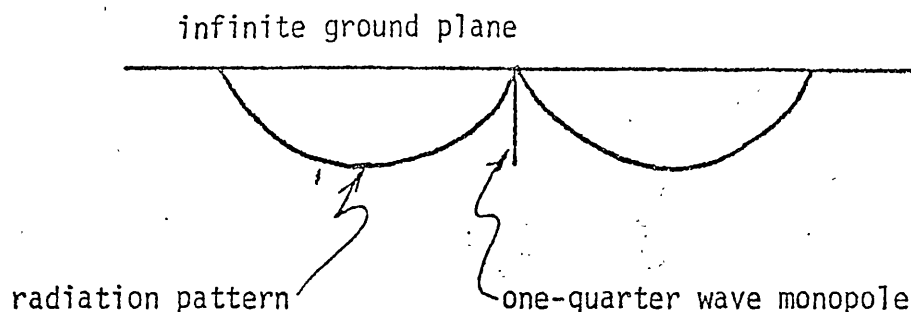


Figure 4
Infinite Ground Plane Pattern

The three-dimensional pattern for the above configuration would be a solid created by the revolution of the above pattern around the axis of the monopole.

For a less than infinite ground plane, the pattern changes. Leitner and Spence show approximate solutions for a disc of radius $\alpha\lambda$, where α is the number of wavelengths. One solution (using Green's Functions) looks like the following, where $\alpha = 1$ in this case:

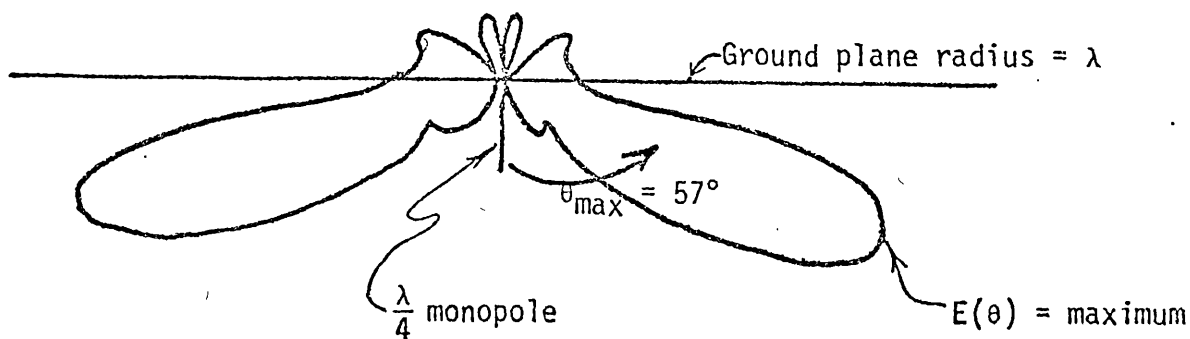


Figure 5
Ground Plane of Radius 1λ

Again, the three-dimensional pattern would be created by revolving above pattern about the axis of the monopole. The case where $\alpha = .48$ looks much the same as Figure 5 except that $\theta_{\max} = 45^\circ$.

Hence, the value of $\theta_{\max}$ varies with the size of the ground plane:

$$\alpha = .48 \rightarrow \theta_{\max} = 45^\circ$$

$$\alpha \rightarrow \infty \rightarrow \theta_{\max} = 90^\circ$$

Determining the pattern for a quarter wave monopole mounted on the belly of an aircraft would be difficult since the ground plane of the antenna would be the airframe of the plane, which is quite different from a disc. However, the following statements can be made:

a. At 915 MHz, $\lambda = 32.8$ cm. For an antenna mounted on the bottom center of the fuselage and centered under the wings of an aircraft, the effective ground plane along with wings and fuselage would be quite large (in these directions α would be much greater than 10λ).

b. Hence, for the proposed antenna mounted on the belly of an aircraft, the pattern would probably look something like the following:

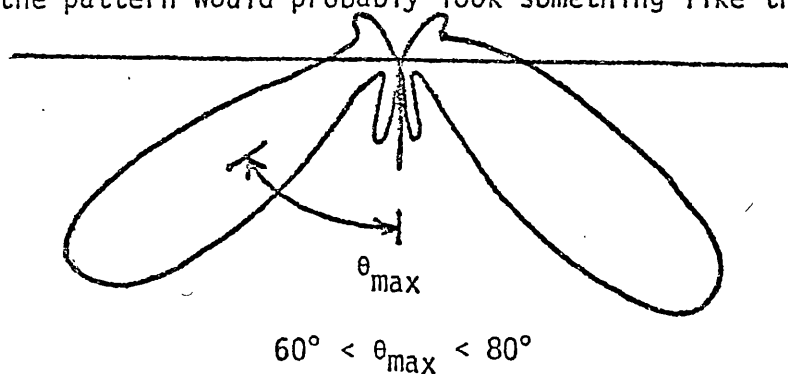


Figure 6

Estimated Pattern For
 $\frac{\lambda}{4}$ Dipole Mounted On Airframe

Radiation at $\theta = \pi/2$ would be less than maximum since the ground plane would not be infinite.

3. Observations on the Transmission System

The maximum radiation lies in the correct direction for effective transmission from the aircraft to the ground station. Hence, the actual radiation pattern would be reasonably close to the optimum pattern.

Nulls in the pattern which might occur at $\theta = 0^\circ$ would not represent a serious problem since the aircraft would seldom be directly over the ground station.

Finally, the use of the proposed antenna would help reduce possible interference with other radio gear at a distance of greater than 30 miles from the aircraft. The antenna pattern is such that the radiated energy is directed downward in a "cone" under the aircraft. Hence, the energy density falls off more rapidly out of the prime communications area than it would for a quarter-wave monopole over an infinite ground plane.

4. Specifications and Design Considerations for Infrared Telemetry From Airplane to Ground: Recorder

The analog signal coming from the infrared scanner aboard the airplane must be stored during the scanning process and transmitted to the ground at a later time when the airplane is in a more favorably attitude for transmission. We would recommend the following record procedure:

The tape recorder to be used is Model R-540-0001 built by Emerson Electric Company, Santa Ana, California. This tape recorder has a variable tape speed capacity of up to 180 inches per second. At a 30 inches per second recording speed, this recorder can record for up to 6 minutes on

one track and up to 12 minutes on two tracks. We would recommend the two-track feature and a record speed of 30 ips. For playback, we recommend a 6 to 1 time compression by running the recorder at 180 ips. This would allow the transmission of a 12-minute signal to occur in 2 minutes which would reduce the length of the airplane flight path by a factor of 6.

We then have a choice of recording direct or recording FM. Since the signal-to-noise ratio can be improved by $3/2\beta^2$ for FM and since we can show dc levels of the analog signal with FM, we recommend FM recording. We would record at 30 ips with $\beta = 1$. The base bandwidth of the signal to be recorded is 104 KHz. Therefore, the IF bandwidth would be $2(1+\beta)F_m = 2(1+1)104 \text{ KHz} = 416 \text{ KHz}$. We recommend a carrier frequency $F_c = 225 \text{ KHz}$. By using this recording technique, we can increase the signal-to-noise ratio of the recording process from 36 db for direct to 38 db for FM. A specification sheet for the tape recorder is attached.

5. The Signal Processing Problem

ERL engineers considering the airplane-to-ground communication system have considered only frequency modulation (FM) systems. A review of why only FM is being considered may be appropriate. The alternatives to FM are various forms of amplitude modulation [standard amplitude modulation (AM), double sideband suppressed carrier (DSB-SC), and single sideband (SSB)], or phase modulation. The phase modulation is so closely related to FM that it will not be considered separately. So the question becomes, why use FM instead of an AM type modulation? The basic reason that FM is preferable is that for a given transmitter power, the received demodulated signal from an FM system has a better signal-to-noise ratio than the demodulated AM signal operating on the same channel. The FM advantage in output signal-to-noise ratio is called the "FM enhancement."

This enhancement is apparent from the equation below where $\frac{S_o}{N_o}_{dB,FM}$ is the FM system output signal-to-noise ratio, $\frac{S_o}{N_o}_{dB,AM}$ is the signal-to-noise ratio of an optimum coherent SSB system, and $10 \log \frac{3}{2}\beta^2$ is the FM enhancement.

$$\frac{S_o}{N_o}_{dB,FM} = \frac{S_o}{N_o}_{dB,AM} + 10 \log \frac{3}{2}\beta^2 \quad (13)$$

Our communication system can be considered as a transmitter at some power level, a channel with a large amount of attenuation plus additive white gaussian noise, and a receiver. The signal entering the receiver has a certain power (S_i) as does the noise (N_w). The receiver demodulates this signal to produce the desired output signal (S_o) which also now has additive noise (N_o). Note the sketch below:

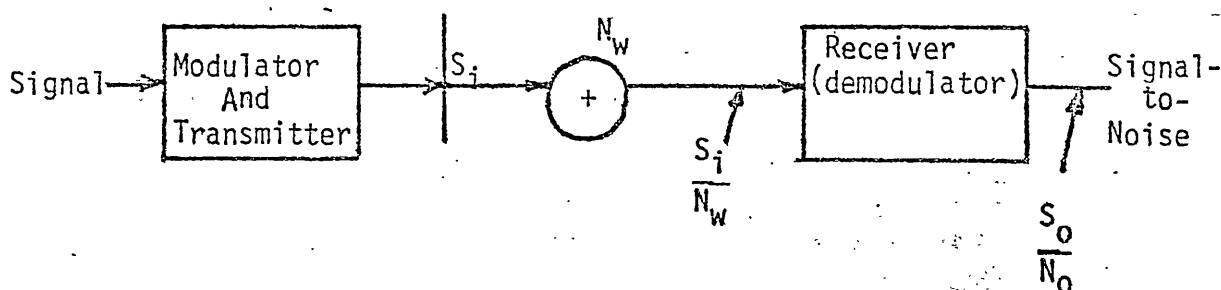


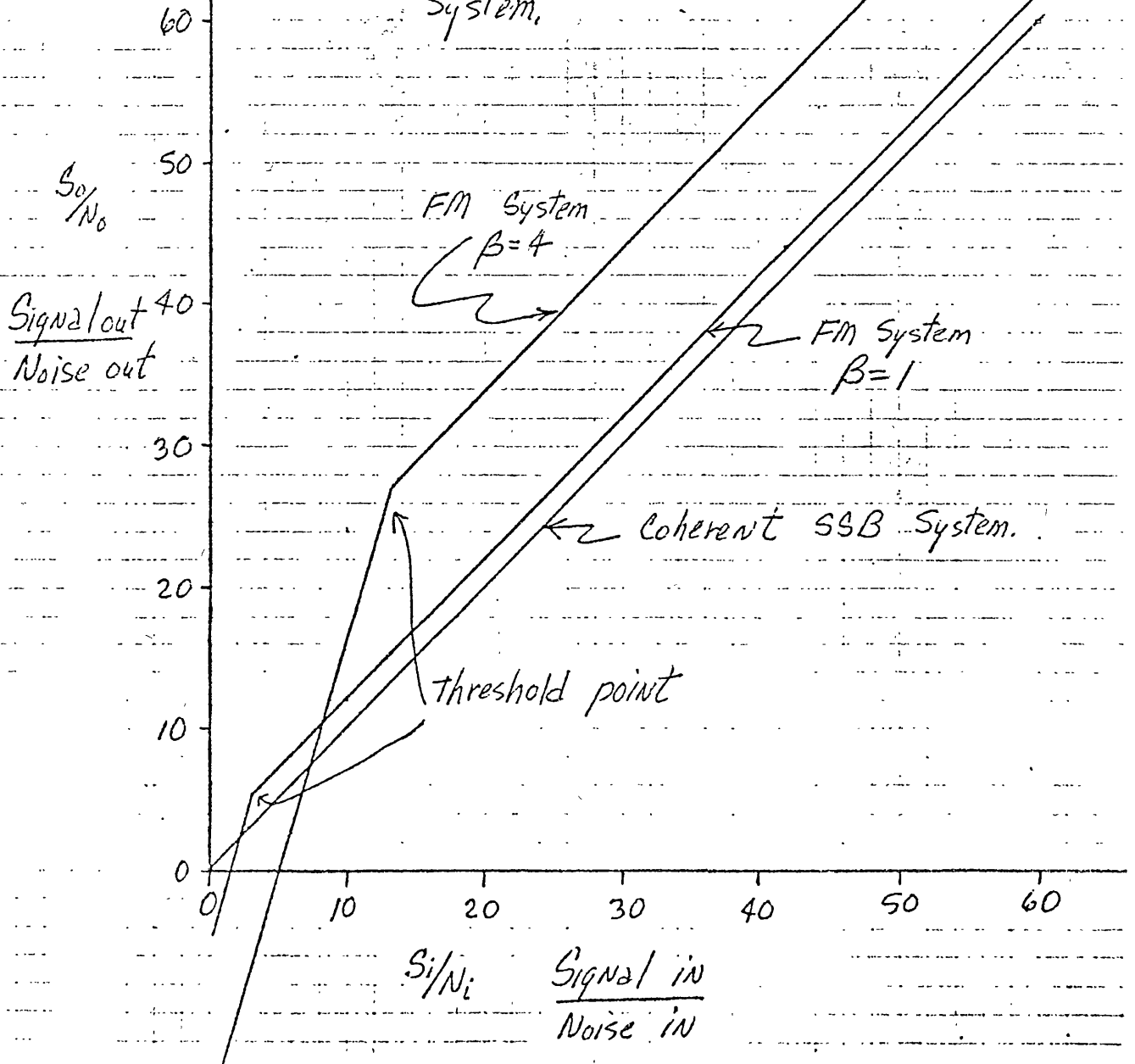
Figure 7

Line Diagram of Communication System

In the above communication system, the receiver input signal-to-noise ratio (signal-to-noise ratio is a measure of signal quality) is a function of the signal power and the additive noise power. In general, there is little one can do with the additive noise level, but the signal power level can be changed (by changing transmitter power or antenna gain). Thus,

Figure 8

Plot of $\frac{S_o}{N_o}$ vs $\frac{S_i}{N_i}$
for two FM systems
and a Single Sideband
System.



to design a communication system, one looks at the desired final signal quality (S_o/N_o) and chooses the other system parameters to produce the desired output quality (ultimately we will do exactly that for this project).

Before getting that far, let's consider the performance of different systems relating to the efficiency of the receiving systems. Figure 8 shows a plot of $(S_o/N_o)_{dB}$ relative to $(S_i/N_w)_{dB}$ for a coherent SSB system and for two FM systems, one with the modulation index $\beta = 1$ and one with a $\beta = 4$. Note that the SSB system S_o/N_o has a 1 to 1 relation with the input S_i/N_w . The two FM systems perform appreciably better after their threshold has been exceeded by the S_i/N_w . The thresholds are defined as that input S_i/N_w where the S_o/N_o begins to increase at the same rate as does the input S_i/N_w . Note at very low S_i/N_w , the SSB system performs better than either FM system, whereas at high S_i/N_w , the FM systems have better performance.

The communication system being designed for the IR scanner should have an output signal-to-noise ratio above 3 db (as will be explained later) so we are really concerned only with areas well beyond the thresholds. Note in this region, that the FM systems certainly are superior, especially the high β system. However, as with all else in nature, a price is paid for this superior performance. The price is in bandwidth. Carson's FM bandwidth rule is $BW = 2(\beta + 1)f_m$ where BW is the system bandwidth, β is the modulation index, and f_m is the bandwidth of the modulating frequency. Thus, the bandwidths needed for the three systems plotted in Figure 8 are $10 f_m$ for the $\beta = 4$ systems, $4 f_m$ for the $\beta = 1$ system, and f_m for the SSB system [e.g., If the baseband (modulating) signal had a bandwidth of 500 kHz, the $\beta = 4$ FM system would have a 5-MHz bandwidth, the $\beta = 1$ system would have a 2 MHz bandwidth, and the SSB system would have a 500-kHz bandwidth.]

Commercial FM equipment is readily available with $\beta = 1$ and $\beta = 4$.

When $\beta = 1$, the equipment is generally called telemetry equipment, whereas if $\beta = 4$, the equipment is called video equipment. The equipment is very similar in nature and either can be considered for the air-to-ground IR scanner data. Before proceeding to show alternate communication system designs, a few more words need to be said about single sideband. Single sideband does not use much bandwidth, but it does have some serious limitations. The largest problem is achieving a reference carrier at the receiver so that coherent detection can take place. Also, the modulation system is more complex than FM. These problems have meant that little SSB work has been done in the telemetry or video transmission fields (even though all commercial TV uses a vestigial SSB transmission for video).

Now let's consider some of the design criteria for the IR scanner data communication system. It is apparent that the data will have to be recorded as the plane flies over the fire area and replayed at a later time to the ground station. Even though in the airplane the signal into the recorder may be considered almost noise-free, the reproduced signal from the tape recorder does have considerable additive noise. Manufacturers measure and publish the expected output signal-to-noise ratio from the recorders. An output signal-to-noise ratio from a tape recorder which might be used may be 35 db (signal power to noise power is 3162 to 1). This S/N is a design limit for the communication system - no matter how good the communication system is the final received S/N cannot exceed 35 db. Note that if the communication system had an output S/N of 35 db, the final output S/N would have been degraded by an additional 3 db relative

to the starting S/N of 35 db, or the final signal S/N would be 32 db. If we designed a communication system with an output S/N of 45 db, we would (according to RF engineers' rule of thumb) be above the 35 db level of output 90% of the time. Or, restating, we can expect no signal fades greater than 10 db 90% of the time and no fades greater than 20 db 99% of the time. Thus, considering that our system will have the capability of determining if a fade has occurred and if it has, the data can be repeated, let's look at the system design for a communication system operating with an output S/N of 45 db.

Design #1

Equipment: FM telemetry transmitter and receiver at 915 MHz
Modulation index $\beta = 1$
Transmitter antenna gain +3 db
Receiving antenna gain +18 db
Receiver noise figure 6.5 db

Baseband
Signal: 624 kHz bandwidth

Path Loss: At 20 miles -123 db

IF: BW = 2.5 MHz

Considering the thermal noise and the receiver noise figures, there will be -104 dbm noise present at the FM discriminator input. In order to have a S/N input of 0 db, a signal level of -104 dbm is needed. In order to have an output S/N of 45 db, we need, from Figure 8, an input S/N of 43.2 db, or an input signal level of $-104 \text{ dbm} + 43.2 \text{ db} = -60.8 \text{ dbm}$.

Now, adding system gains and losses to determine needed transmitter power we have:

path loss	-123 db
antenna gains	+ 21 db
	<u>-102 db</u>

The signal level needed (-60.8 dbm) at the receiver corresponds to (+102 - 60.8) 41.2 dbm needed at the transmitter. When one considers that signal fades occur less often between airplanes and ground than our rule of thumb indicates (which was for ground-to-ground), and that the 20-mile path length was a maximum, a 20-watt transmitter (+43 dbm) should work well. Such a transmitter will cost approximately \$7,000 while the receiver will cost \$6,000.

Design #2

Equipment: FM video transmitter and receiver at 915 MHz
 Modulation index $\beta = 4$
 Transmitting antenna gain +3 db
 Receiving antenna gain +18 db
 Receiver noise figure 6.5 db

Baseband
 Signal: 624 kHz bandwidth

Path Loss: At 20 miles: -123 db

IF: BW = 6.24 MHz

Due to thermal noise and receiver noise figures, there will be -99.5 dbm of noise at the FM discriminator input and a -99.5 dbm signal will give a 0 db S/N input. To get an output S/N of 45 db, we have, from Figure 8, that the input S/N must be 31 db. To generate that, we will need a signal level at the receiver of -68.5 dbm (-99.5 + 31).

With a path loss $-123 + 21 = -102$ db, we will need a transmit signal of $(-102 + 68.5)$ 33.5 dbm. Now, a 20-watt (+43 dbm) transmitter will allow a fade of 19.5 db to occur and the communication system will only degrade to an output S/N of 35 db.

A video transmitter will cost about \$6,000 and the receiver will cost about \$6,000 for 915 MHz.

Design #3

Equipment: FM telemetry system at 1.5 GHz (otherwise same as Design #1, except path loss)

Analysis: The same receiver specifications are valid at 1.5 GHz as at 915 MHz. The path loss has increased by 4 db at 20 miles. Higher gain antennas are available at 1.5 GHz so the additional path loss can be made up with more directional antennas. However, the tracking problem is now slightly more difficult. Otherwise, the system operation should be similar to that of the telemetry equipment at 915 MHz.

Design #4

Equipment: FM video system at 1.5 GHz.

Analysis: Again, the path loss has increased by 4 db, but again that loss could be gained in antenna gain. Then the 1.5 GHz video system will operate as the 915 MHz video system.

III. CONCLUSIONS

The report indicates that technical progress on the study has been significant during this reporting period. A number of trade-off areas have appeared and consideration of these areas has led to the type of system discussed in this report. Several specific recommendations can be made at this point, and they appear below:

1. A complete system can be laid out at this point that could do the job (as the ERL engineers have defined it).

2. Such a system should be "blocked together" on paper and thoroughly discussed by the Forest Service and ERL personnel (i.e., in person).

3. If the system is fairly close to what the Forest Service feels will do the job, a write-up should be done on the system and it should be submitted to IRAQ.

4. The submission of IRAQ should include a request for a frequency allocation.

5. The IRAQ submission should be done as early as possible to insure a frequency allocation by summer 1975.

6. It is suggested that the ERL project be continued until 1 June 1975 at no increase in funding. In this way, continuing engineering help will be available up until June.

IV. WORK FOR THE NEXT PERIOD

During the next period, the work will continue somewhat along the same two major lines. A technical meeting between the ERL engineers and the Forest Service is also planned to discuss progress and adjust the direction of the project, if necessary. ERL engineers also plan to obtain more information on specific gear like the recorder. It is possible that some actual gear demonstrations can be arranged to see if the gear can actually do the job.

APPENDIX E

This appendix contains an analysis pertaining to a basic PCM system as applied to the infrared data transmission problem. It is assumed that a 5-volt peak-to-peak video signal is to be quantized and transmitted over a pulse code modulation communication system. White Gaussian noise is assumed to be added to the transmitted signal. The output medium is a cathode-ray tube producing an image on black and white film with a 16-gray scale tonal range.

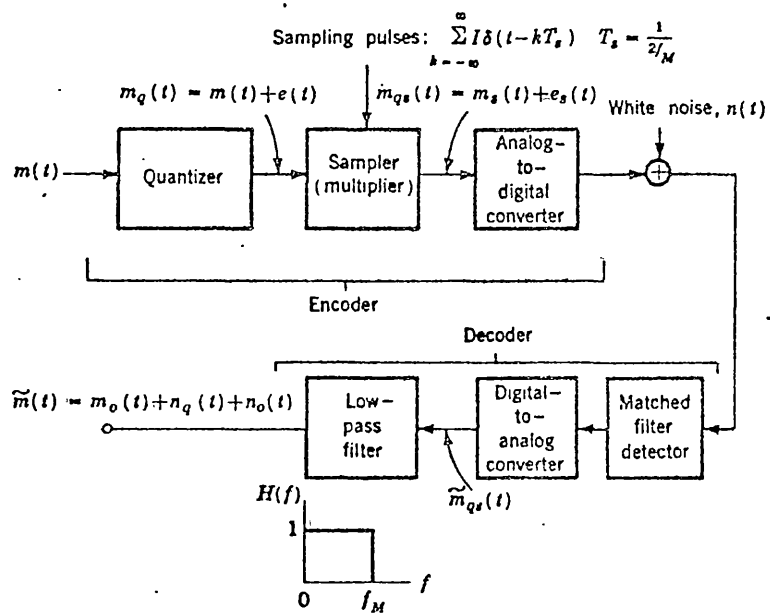
The questions herein considered are: (1) How is P_e (error probability per bit) and S_o/N_o (output signal-to-noise ratio) affected by changing the number of quantization levels of the video signal? (2) What is sacrificed by changing the number of quantization levels? (3) What number would make the best use of the output medium?

It is obvious that less than 16 quantization levels would not make full use of the tonal gradation capability of the system. Therefore, 16 levels encoded by four-bit words is the minimum that will be considered. One is tempted to reason that more than 16 quantization levels would exceed the tonal capability of the system and would not be a useful addition. To determine the validity of this argument, the results of 32 quantization levels encoded by five-bit words will be compared with a 16-level system.

Paralleling the development in Taub and Schilling¹, the PCM system under discussion is assumed to be the form shown in Figure E-1. Assuming an M level quantizer encoded with N -bit words and no white Gaussian noise (quantization noise only), the output signal to quantization noise ratio is:

FIGURE E-1

A Binary PCM Encoder-Decoder



$$\frac{S_o}{N_q} = M^2 = (2^N)^2 = 2^{2N} \quad (1)$$

where S_o/N_q is the limiting value of output signal-to-noise ratio in a PCM system (see Figure 3).

If white Gaussian noise and phase shift keying (PSK) or direct transmission is considered, probability of error for the matched filter (see Figure 1) is:

$$P_e = \frac{1}{2} \operatorname{erfc} \sqrt{\frac{E_s}{\eta}} \quad (2)$$

where E_s = signal energy of a bit,

$\eta/2$ = two-sided noise power spectral density.

Output signal-to-noise ratio is then:

$$\frac{S_o}{N_o} = \frac{S_o}{N_q + N_{th}} = \frac{2^{2N}}{1 + (4P_e)(2^{2N})} = \frac{2^{2N}}{1 + 2^{2N+1} \operatorname{erfc} \sqrt{E_s/\eta}} \quad (3)$$

$$E_s = S_i \frac{T_s}{N} = \frac{S_i}{2f_M N} = \text{energy/bit} \quad (4)$$

where S_i = receiver signal power

T_s = sample interval

N = number of bits/code word

T_s/N = bit duration

$T_s = 1/2 f_M$ (implying Nyquist rate sampling)

f_M = maximum frequency of original video signal

N_{th} = thermal or Gaussian noise

Therefore, for PSK or direct transmission:

$$\frac{S_o}{N_o} = \frac{2^{2N}}{1 + 2^{2N+1} \operatorname{erfc} \sqrt{\frac{1}{2N} \frac{S_i}{nf_M}}} \quad (5)$$

Table 1 gives tabulated values for P_e/bit and $\log_{10} P_e$ as a function of S_i/nf_M and N . Table 2 gives tabulated values for S_o/N_o and $(S_o/N_o)_{\text{dB}}$ as a function of the same variables. Figure E-2 is a plot of $\log_{10}(P_e/\text{bit})$ as a function of input signal-to-noise ratio and N . Figure E-3 displays output signal-to-noise ratio as a function of the same independent variable as in Figure E-2.

It is interesting to note that the probability of error/bit is greater for larger numbers of quantization levels. This is a reasonable result because one would expect that a larger noise level would be necessary to cause a signal excursion out of a wider quantization region. Does this mean that five quantization levels are less satisfactory than four? The answer depends on input signal-to-noise ratio as shown in Figure E-3. If $S_i/nf_M < 16.1$ dB, a system using 16 quantization levels ($N = 4$) gives a larger output signal-to-noise ratio. The maximum difference is approximately 2 dB at $S_i/nf_M = 14$ dB. If, however, the input signal-to-noise ratio is greater than 20 dB (a more normal condition), the system using 32 quantization levels ($N = 5$) is 6 dB better in output signal-to-noise ratio than the $N = 4$ system. If $S_i/nf_M > 20$ dB, both systems are quantization noise limited. The quantization noise dominates the channel noise and $S_o/N_o = 2^{2N}$.

What does this 6 dB increase in S_o/N_o mean in terms of image improvement? J. S. Mayo² has done experimental studies correlating the number of quantization levels of a video signal and television picture

TABLE 1

$S_i/\eta f_M$ (dB)	P_e/Bit (N = 4)	P_e/Bit (N = 5)	$\text{Log}_{10} P_e$ (N = 4)	$\text{Log}_{10} P_e$ (N = 5)
0	0.500	0.500	- 0.30	- 0.30
2	0.263	0.286	- 0.58	- 0.54
4	0.214	0.240	- 0.67	- 0.62
6	0.161	0.191	- 0.79	- 0.72
8	0.104	0.132	- 0.98	- 0.88
10	0.565×10^{-1}	0.787×10^{-1}	- 1.25	- 1.10
12	0.230×10^{-1}	0.375×10^{-1}	- 1.64	- 1.43
14	0.620×10^{-2}	0.125×10^{-1}	- 2.21	- 1.90
16	0.930×10^{-3}	0.291×10^{-2}	- 3.03	- 2.54
18	0.395×10^{-4}	0.113×10^{-4}	- 4.40	- 3.95
20	0.299×10^{-6}	0.412×10^{-5}	- 6.52	- 5.38
22	0.160×10^{-9}	0.935×10^{-8}	- 9.80	- 8.03
24	0.121×10^{-14}	0.710×10^{-12}	-14.9	-12.2
26	0.104×10^{-22}	0.234×10^{-18}	-22.0	-18.6
28	0.183×10^{-35}	0.149×10^{-28}	-35.7	-28.8
30	0.131×10^{-55}	0.106×10^{-44}	-55.9	-45.0

TABLE 2

S_i/nf_M (dB)	$S_o/N_{o_{PSK}}$ (N = 4)	$S_o/N_{o_{PSK}}$ (N = 5)	S_o/N_o (dB) (N = 4)	S_o/N_o (dB) (N = 5)
0	1	1	0	0
2	1.89	1.74	2.76	2.40
4	2.32	2.08	3.67	3.18
6	3.07	2.63	4.87	4.18
8	4.72	3.77	6.74	5.76
10	8.56	6.32	9.32	8.00
12	20	13.2	13.0	11.2
14	61.4	38.5	17.9	15.9
16	173.5	147.	22.4	21.7
18	251.	832.	24.0	29.2
20	256.	1005.	24.1	30.0
22	256.	1024.	24.1	30.01
24	256.	1024.	24.1	30.01
26	256.	1024.	24.1	30.01
28	256.	1024.	24.1	30.01
30	256.	1024.	24.1	30.01

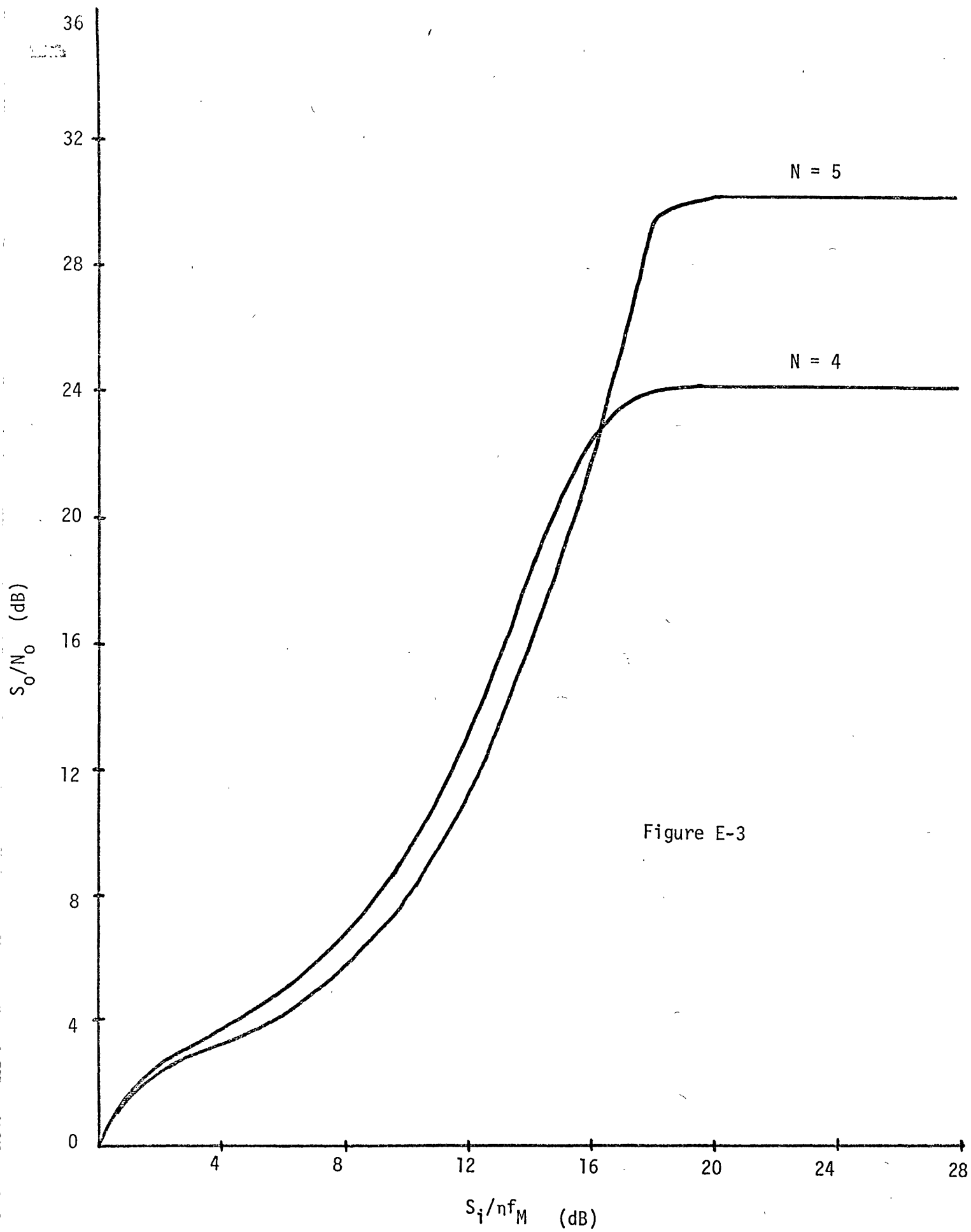


Figure E-3

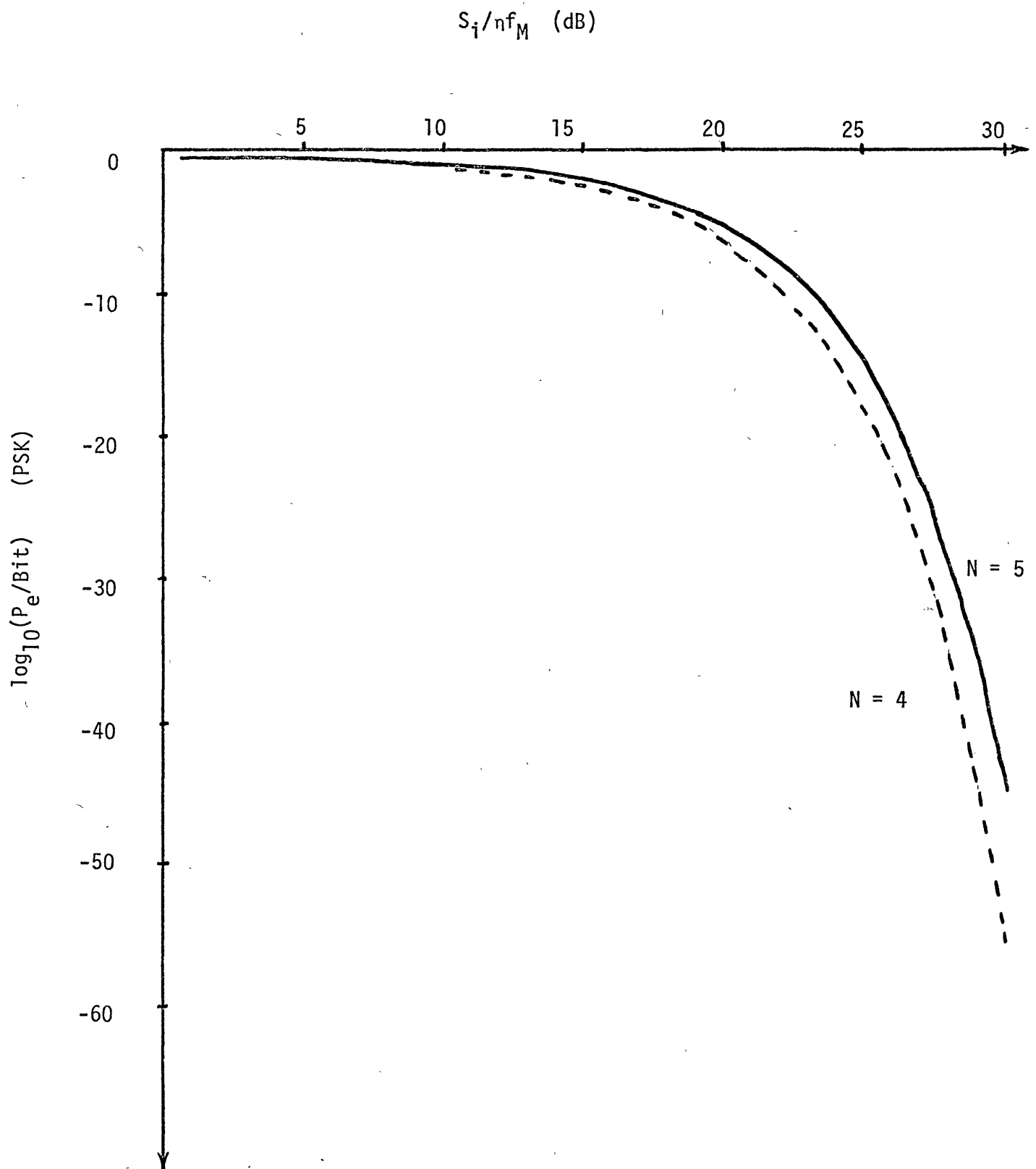


Figure E-2

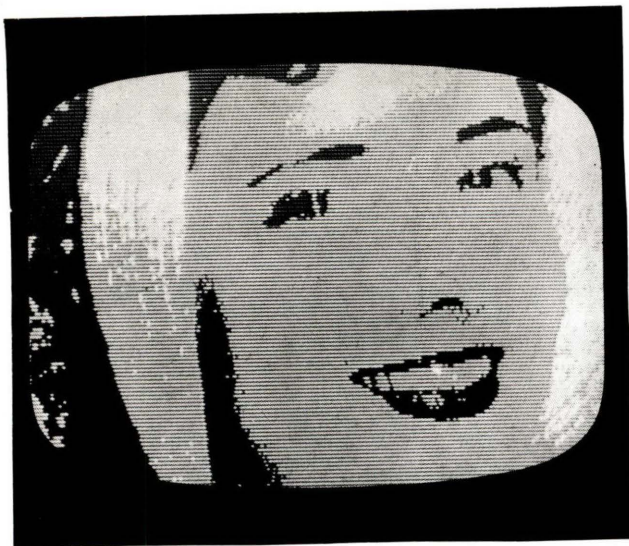
quality. Photographs of black and white TV images are shown on Page 102, Reference 2, for $N = 2$, $N = 3$, $N = 4$, and $N = 5$ (corresponding to approximately 4, 8, 16, and 32 quantization levels, respectively). Not all levels are visible in the display because some are used for synchronization. There is an obvious improvement in image quality when the number of quantization levels is increased from 16 to 32. However, there is a question if a map needs the tonal quality of a pretty girl's picture?

What is the price that must be paid for this image improvement? If the analog video signal has bandwidth f_M Hz, it must be sampled $2 N f_M$ pulses/second transmitted. This requires $N f_M$ Hz bandwidth for the baseband signal to be modulated in the ideal case, and approximately $1.4 N f_M$ Hz bandwidth in present PCM systems. Therefore, if $N = 4$, $BW = 4 f_M$ Hz in the ideal ($5.6 f_M$ Hz in practice), and if $N = 5$, $BW = 5 f_M$ Hz in the ideal ($7 f_M$ Hz in practice). Another problem is an increase in complexity of the encoder/decoder system as N increases. This is probably not of significant concern for low values of N .

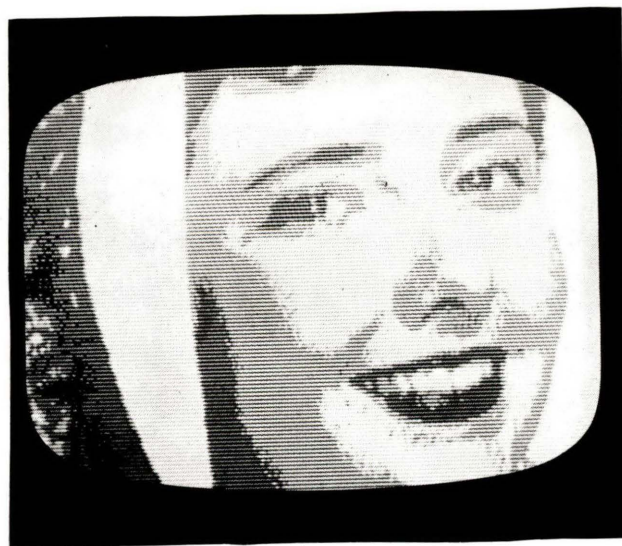
The conclusions that may be drawn are: (1) If input signal-to-noise ratio (S_i/nf_M) is greater than 20 dB, a 25% improvement in output signal-to-noise ratio (S_o/N_o) is gained by using 32 quantization levels ($N = 5$) instead of 16 levels ($N = 4$). (2) If $(\frac{S_i}{nf_M}) < 16.1$ dB (unlikely), then the $(\frac{S_o}{N_o})_{N=4} > (\frac{S_o}{N_o})_{N=5}$, but not by more than 2 dB. (3) The 25% improvement in S_o/N_o results in a gain in television image quality capable of being detected and reproduced by ordinary printing techniques. (4) The minimum bandwidth requirement for the $N = 4$ case is $BW = 4 f_M$ where f_M = bandwidth of the original analog video signal. If $N = 5$, $BW = 5 f_M$ (ideal case). (5) A PCM system requires more bandwidth and complexity than an FM analog system.

REFERENCES

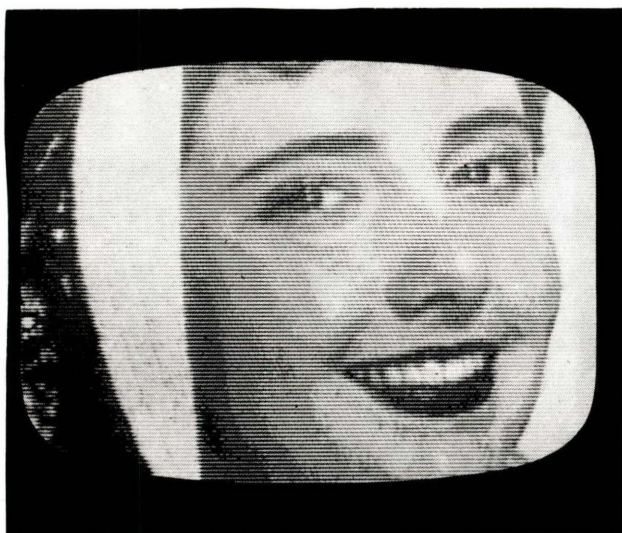
1. Principles of Communication Systems, Taub and Schilling, McGraw-Hill, 1971, Pgs. 391-400.
2. Pulse Code Modulation, J. S. Mayo, Scientific American, March 1968, Pgs. 102-108.
3. The Philosophy of PCM, Oliver, Pierce, Shannon, Proc. of IRE, November 1948, Pgs. 1,324-1,331.



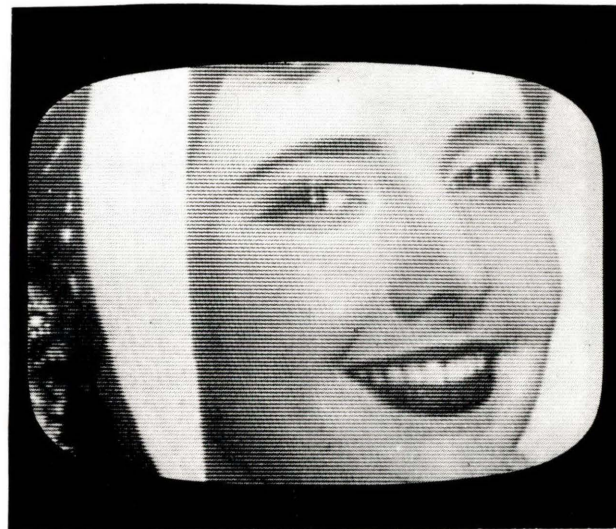
$N = 2$



$N = 3$



$N = 4$



$N = 5$

Figure E-4

Photographs of TV Images Constructed
From Quantized Samples.
(The number of quantized levels was 2^N where N
is shown under each photograph.)